OBJECTIVE QUALITY ASSESSMENT OF MODIFIED ATMOSPHERE STORED ZUCCHINI SLICES USING ELECTRONIC NOSE, MACHINE VISION AND INSTRON

By

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OBJECTIVE QUALITY ASSESSMENT OF MODIFIED ATMOSPHERE STORED ZUCCHINI SLICES USING ELECTRONIC NOSE, MACHINE VISION AND INSTRON

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Modified Atmosphere Storage (MAP) is an important method to extend shelf life of food. Using electronic nose (EN), machine vision (MV) and Instron provides quality evaluation of foods. Our objective was to measure quality changes of MAP stored sliced zucchini using EN, MV and Instron, and correlate these data with sensory parameters and microbial counts. Zucchini were washed, sliced, and dipped in chlorinated water for 2 min, and spin-dried. During the controlled atmosphere (CA) study, containers were attached to the flow-through system during storage (10˚C, RH=95%). Samples were subjected to 2 different CA conditions ($2\%O_2+7\%CO_2$ and $2\%O_2+15\%CO_2$, balance N_2) and air. During the first and second studies, slices were put into two different plastic bags (~280g/ bag). Bags (P1= first bag; P2= second bag) were flushed with gas ($2\%O_2+15\%CO_2$ balance N_2, or air), sealed and stored (5˚C, RH=95%). Samples were evaluated using EN, MV and Instron, and sensory quality parameters. Aerobic microbial counts were performed. EN and MV data were evaluated by discriminant function analysis (DFA). Correct classification rates (CCR) and cross validation analysis were performed. Canonical correlation was calculated between objective readings and sensory evaluations.

CCR for color data were 100% for air, 7% and 15%CO_2 treatments for the CA experiment. CCR for P1-Air, P2-Air, P1-CO_2 and P2-CO_2 were 96%, 98%, 97%, and 98%, in the first experiment and 88%, 96%, 94%, and 93%, in the second experiment, respectively. DFA of EN data gave more than 98%, 94% and 96% CCR for all treatments in CA, first and second experiments, respectively. MAP significantly reduced microbial growth, discoloration and off-odor, and maintained hardness, crispness and zucchini aroma ($p>0.001$) for CA and second experiment. Average L* a* b* values and % color changes showed that the best color preservation was with CO_2 treatments. The correlations among different color blocks, e-nose sensor readings, textural parameters, and microbial loads with different sensory attributes were significant. This project suggests that the use of objective methods, correlated to sensory results, can save time, cost, and increase reliability of food quality evaluation.

CHAPTER 1
INTRODUCTION

There have been many developments in the area of fresh-cut vegetables and fruits due to higher consumer demand for them in recent years. Storage of sliced zucchini is of interest because it is a source of vitamins C and A, and it is grown throughout the world, although storage life is limited because it is very perishable and chilling sensitive (Izumi et al., 1996). Due to physiological aging, biochemical changes, and microbial spoilage, quick degeneration results in changes in color, texture and flavor in sliced zucchini (Mencarelli, 1987). Modified atmosphere packaging (MAP) extends the shelf life in fresh-cut products by controlling biochemical changes, microbial spoilage, and degeneration that occur over time and that results in changes in color, texture, and flavor. Summer squash has an average shelf-life of 5 to 14 days when stored at 5-10°C at 90% relative humidity. The recommended gas compositions for fresh-cut zucchini squash stored in cold temperatures is 2-7 %O_2 and 5-8 % CO_2 for modified atmosphere (MA).

The degradation of fresh-cut vegetables is a complex process that includes both microbial spoilage and a number of physico-chemical and biochemical modifications that mainly affect quality characteristics (Riva et al., 2001). Color, odor, and texture of the products are some of the quality characteristics. These play an important role in the marketing of the product since they are directly evaluated by the consumer (Salunkhe et al., 1991). It is well known that aging affects the flavor characteristics of vegetables and the production of off-odors, due to bacterial activity or anoxic conditions, and limits their shelf life (Nguyen and Carlin, 1994). Therefore, it is very important to quantify changes in quality characteristics during storage. Current practices for the evaluation of vegetable quality characteristics are based on the use of a sensory panel and the analysis of total bacterial count that requires an incubation time of about 2 days. These methods are expensive and time consuming (Galli and Franzetti, 1991). Using electronic nose (EN), machine vision (MV), and Instron provides objective quality evaluation of fresh-cut products in a short period of time with less cost. These measures can rapidly and quantitatively determine quality of MAP stored sliced zucchini. The combination of these data is an improvement towards determination of the overall quality of foods. Both EN and MV data can be used in pattern recognition for objective classification of sliced zucchini stored under MA.

The objectives of this study were i) to subject sliced zucchini squash to different modified atmosphere conditions and store these samples at a constant temperature until decay, ii) to measure organoleptic quality parameters of these samples, their microbial numbers, and objective quality parameters using Neotronics electronic-nose, machine vision system, and Instron, and iii) to evaluate and correlate statistically the relationship between organoleptic evaluations and objective readings.

CHAPTER 2
LITERATURE REVIEW

Importance of Fresh-Cut Vegetables

Fresh-cut products consist of fresh fruits and vegetables transformed into a 100% usable product (International Fresh-Cut Produce Association, 1998). They are found mainly as vegetable stick snacks, packaged tossed salads, chilled peach halves, peeled and cored whole pineapple cylinders, shelled fresh legumes, and microwaveable fresh vegetable trays (Shewfelt, 1987). Minimal or light processing operations are defined as procedures that do not affect the "fresh-like" quality of the fruit or vegetable. These operations may be washing, sorting, trimming, peeling, slicing, or chopping. However, if the product is wounded, shelf life is often diminished (Burns, 1995).

The fresh-cut produce industry was predicting a market of $4 to $8 billion/year by the year 2000 in the U.S. (Hurst and Schuler, 1992). The International Fresh-Cut Produce Association (1998) reports that sales of fresh-cut fruits and vegetables average a $10-12 billion per year, which is about 10% of total produce sales (including retail and food service sales). Packaged salads alone topped $1.6 billion in retail sales in 1999, a 15.9% increase from the year before.

Consumers have become more careful and health-conscious about their food choices although they have less time to prepare healthful meals. They demand convenient, ready-to-use, and ready-to-eat fruits and vegetables with a fresh like quality and containing only natural ingredients. Three percent of consumers interviewed said they purchased packaged fresh produce in the first six months of 1998 (Packer Fresh Trends, 1999). Nearly one third of respondents and 38 % of households with children stated they will be eating more produce (Packer Fresh Trends, 1999). More than one-fourth of consumers are buying more packaged produce than a year ago (Packer Fresh Trends, 1999). As a result, the market demand for "minimally processed" or "fresh-cut" fruits and vegetables has rapidly increased. Only 34.8% of stores offer produce, indicating ample opportunities to capture part of this market. Fresh-cut produce currently totals about 15-20% of food service business sales. Produce represents only 0.5% of convenience store merchandise sales, which presents another opportunity. Food service operators realize a savings of almost 15% over bulk produce. In Europe, the market for minimally processed fruits and vegetables grew rapidly in the early 1990s (Day and Gorris, 1993). In the U.S., it was believed that the market share of fresh-cut produce would account for 25% of all produce sales in the retail market by the year 2000 (Garret, 1994).

Potential Problems With Minimally Processed Materials

One of the crucial problems in minimal processing is undesirable physiological changes. Compartmentation of enzymes and substrates is destroyed by the loss of cellular integrity at the cut surface of the fruit or vegetable. Results are browning reactions and formation of secondary metabolites. Senescence and off-flavors may develop while respiration and ethylene production increase near the cut surface. Also, a favorable medium for fungal and bacterial growth can form. As the produce is handled further, contamination and microbial growth can lead to health risks. Undesirable physiological changes that adversely effect the quality of the lightly processed products can be controlled by various approaches such as refrigeration, humidity control, addition of chemicals, and modified atmospheres, with appropriate packaging. Edible coatings and films have been used with some commodities to form useful barriers to moisture, oxygen, and carbon dioxide, while improving package recyclability (Burns, 1995).

Preparation of fresh-cut produce causes significant physical damage to tissues and cells, and these products are considered highly perishable (Cantwell, 1995b). The fresh-cut products are still living and therefore undergoing physiological processes (Rolle and Chism, 1987; Kim and Lee, 1992). They need to use the nutritional reserves as energy source in order to sustain respiration processes and thus life, since they cannot get nutrients from the plant (Kim and Lee, 1992). If an "energized state" cannot be maintained in the tissues, they will deteriorate and die (Rolle and Chism, 1987).

Brecht (1995) mentioned that fresh-cut products show physiology similar to wounded tissues including higher respiration rates, increased ethylene production, decompartmentation of enzymes and substrates by cell disruption, and sometimes, induction of wound-healing processes. Physiological changes also include water loss, lipid degradation (Brecht, 1995), accumulation of secondary metabolites and other biochemical processes, generally followed by color, flavor, texture, and nutritional changes (Cantwell, 1992; Reyes, 1996) with consequent promotion of faster degradation of the product.

Benefits of Modified Atmosphere in Packaged Fresh-Cut Products

A key limitation of fresh-cut products is their short shelf life. When they are processed, injury to the tissues promotes increased metabolic reactions leading to premature senescence and decay, facilitated by microbial growth (Cantwell, 1992, 1995b; Brecht, 1995; Schlimme, 1995; Watada et al., 1996). Encouraging results in increasing the shelf life of these products have been obtained by modified atmosphere, controlled atmosphere, and refrigerated storage.

Low temperatures, as well as low O_2 and high CO_2 concentrations, reduce respiration rates and inhibit microbial growth, and therefore are effective in maintaining the quality of fresh-cut produce such as packed salads (Kader et al., 1989). If used separately, low O_2 or high CO_2 levels have reduced efficacy (Peiser et al., 1997; Portela et al., 1997). Temperature, $O_{2,}$ and CO_2 controls must be used very carefully and should be monitored since they can cause chilling or freezing injury, irregular ripening, anaerobic metabolism, off-flavor, and off-color development, in parallel with the benefits they promote in fresh produce (Cantwell, 1992; Kader, 1992; Brecht, 1995; Schlimme, 1995). Optimal storage temperatures and gas concentrations may differ significantly between whole fruits and fresh-cut produce (Cantwell, 1995b). The threshold for low O_2 or high CO_2 tolerance of the produce may limit the benefits that these gases contribute to final product quality (Peiser et al., 1997). It is important to develop guidelines specific for each product.

Modified atmosphere packaging (MAP) was used to extend the shelf-life of shredded vegetables by inhibiting metabolic activity, decay, and especially ethylene biosynthesis and action (Beuchat and Brackett,1990; Ballantyne et al., 1988; Kader,1986). The conditions recommended for most vegetables are low O_2 (2 % to 3%) and high CO_2 (3% to 6%). (Kaji et al., 1993). Semipermeable plastic films are chosen for MAP so that the film permeability and product respiration can combine to produce a desirable, steady-state atmosphere within the package (Kader et al., 1989). The tolerance of fresh-cut products to low O_2 and elevated CO_2 concentrations has been determined in long term storage tests. Fresh cuts products have higher levels of metabolic activity, including higher respiration rates and higher ethylene production; therefore, storage times are generally shorter (Schlimme, 1995). The internal package atmosphere is controlled by many factors, including the nature and thickness of packaging polymer and its surface area relative to the weight and kind of fresh-cut produce. Thus, undesirable results can be obtained if extensive research and empirical testing of the product-package-temperature interactions are not carried out (Schlimme, 1995).

Many types of plastic films are available for packaging, but relatively a few of them have been used for fresh produce. Low-density polyethylene, polyvinylchloride, and polypropylene are the main films used to package fruits and vegetables. Polystyrene has been used, but polyvinylidene, and polyester have such low gas permeabilities that they would be suitable only for commodities with very low respiration rates. However, perforating these films can expand their use to many commodities. Recent advances in technology of manufacturing polymeric films have permitted tailoring films for specific gas diffusion needs of some fruit, vegetables, and their products. The combination of ethylene vinyl acetate with oriented polypropylene and low-density polyethylene or the combination of ceramic materials with polyethylene have good heat-sealing properties (Ahvenainen and Hume,1994). The plastic must be flexible and easy to use, and strong enough to survive normal handling operations. Benefits of film packaging, other than creation of MA conditions can include maintenance of high relative humidity and reduction of water loss; improved sanitation by reducing contamination of the products during handling; minimized surface abrasions by avoiding contact between the commodity and the shipping container; reduced spread of decay from one produce to another; use of the film as carrier of fungicides, scald inhibitors, ethylene absorbers, or other chemicals; brand identification and providing relevant information to consumer (Kader and Watkins, 2000). Another possible method for extending the shelf life of fresh-cut fruits and vegetables is the use of edible-coatings, thin layers of material that can be eaten by the consumer as part of the food product (Ahvenainen, 1996).

To maintain the desired gas levels within the package, two factors must be considered. First, the produce in the package is continually respiring and consuming O_2 while producing CO_2. Second, O_2 will diffuse into the bag and CO_2 will diffuse out. This occurs because the package contains low levels of O_2 and high levels of CO_2, and atmosphere outside the package contains 21% O_2 and trace levels of CO_2. To control the atmosphere within the package successfully, the permeability of the packaging film must be selected such that rate of O_2 diffusion into the package equals the rate of O_2 consumption by the commodity (KO_2). Similarly, the rate of CO_2 efflux should correspond to the rate of respiratory CO_2 production (ECO_2) (Segall and Scanlon, 1996).

Much work has been done to model the gas composition in the package atmospheres of whole produce (Wiley, 1994; Kader et al., 1989). Most attempts recognize the interaction of produce respiration and the diffusion of gases through the package (Ahvenainen, 1996) . However, even if an exact model and gas balance inside the package could be created, it would be only possible to extend the shelf-life by a few more days (Ahvenainen, 1996). This is because respiration is not the only cause of quality changes in fresh-cut products: enzyme and microbial activity, and in some cases, ethylene also result in the development of off-colors, odors, and tastes (Ahvenainen, 1996).

Reyes (1996) correlated shelf-life and respiration rate by explaining that the shelf-life of fresh vegetables and fresh-cut products decreases as respiration rate increases. Respiration rate may increase from <1 to 8-fold in most fresh-cut fruits and vegetables as compared to whole products. The rise in the respiration rate might be a result of biosynthesis of secondary metabolites responsible for wound healing. Another factor related to the respiration is the activation of enzymes typically involved in respiratory processes. Since there is no heat treatment for fresh-cut products, enzyme inactivation does not happen (Kim and Lee, 1992).

Increased ethylene production due to mechanical damage has been reported for a variety of produce. Some of the physiological changes by elevated ethylene concentration are increased senescence and respiratory activity, increased activity of enzymes, and general softening of texture (Lafuente et al., 1989).

Respiration rate is determined by measuring the consumption of O_2 or the generation of CO_2 over time (Kay, 1991). This may be done in a system in which the commodity is sealed in an air-tight container and samples of the atmosphere are analyzed regularly. As there is no exchange of gasses with the outside, the O_2 levels drop continuously while the CO_2 levels increase. The result is a further inhibition of respiration until the respiration rate reaches equilibrium. Plotting respiration rate versus the corresponding gas concentrations allows prediction of the respiration rate at any desired O_2 and CO_2 concentrations (Lee, 1986).

The form of the mathematical model that best predicts respiration behavior is a matter of debate. Some researchers have argued that the presence of CO_2 does not significantly affect the rate of O_2 consumption and that the model can neglect the presence of CO_2 (Andrich et al., 1991; Cameron et al., 1989; Gong and Corey, 1994; Joles et al., 1994; Jurin and Karel, 1963; Lopez-Briones et al., 1993). However, other researchers have shown that the KO_2 of a given commodity depends on the concentration of CO_2 in the atmosphere (Herner, 1987). Several researchers used models based on enzymatic (Haggar et al., 1992; Lee et al., 1991, 1994; Yam et al., 1993), quadratic (Lee, 1986), or linear (Hayakawa, et al., 1975) mathematical functions.

The storage time required for cut produce is shorter than for whole products, in atmospheres that might injure products over longer time periods. Also, quality control factors, such as temperature, are more consistently applied because the products tend to be of high value and because of heightened concern about food safety.

Quality degradation is retarded by decreasing the temperature of plant tissue to a point just above the freezing point of non-chilling sensitive tissues or just above the point at which chilling injury occurs for sensitive produce. Q_{10} values for many fruits and vegetables are highest (up to 7) between 1 and 10°C, and are usually between 2 and 3 above 10°C (Wills et al., 1989). Thus, for non-chilling sensitive lightly processed produce, maintaining product temperatures at 1 or 2°C above the freezing point may increase shelf-life by at least three- to fivefold as compared to storage at 10°C. Hence, temperature abuse during processing, distribution, and merchandising is to be strictly avoided to achieve maximum shelf life (Schlimme, 1995). Also respiration and ethylene production rates are minimized when fresh products are kept at low temperature. Low temperatures slow the ripening and other metabolic processes, reduce deterioration, and can minimize the effects of ethylene (Schlimme, 1995).

Current Applications of MAP for Fresh and Minimally Processed Products

Difference between MA and CA that MA can be created inside a package either passively through product respiration or by actively replacing the atmosphere in the package with a desired gas mixture. With passive MA, if product and film permeability are properly matched, the desired MA can evolve within the package by respiration. The gas permeability of the selected film must allow O_2 to enter the package at the same rate as the consumption of O_2 by the produce. Similarly, CO_2 must permeate from the package to offset the production of CO_2 by the produce. The desired MA has to be established within 1-2 days without anoxic conditions or high levels of CO_2 that may induce a fermentative metabolism (Gorny, 1997).

The design of MAP requires permeation properties of polymeric films and the respiration rates of fresh produce placed inside the packages. Mathematical models are useful in determining the changes in gas concentrations in the package during storage. Several mathematical models have been tested but few are used commercially. Most data on film permeability are generated at a single temperature and often at low relative humidity. The responses of film permeability to temperature between 0°C and 20°C and relative humidities between 85% and 95% have to be determined. Changes in respiratory quotient in response to changing atmospheres could have a great effect on evolving atmospheres inside packages (Kader and Watkins, 2000). When a fruit or vegetable is subjected to atmospheres outside safe limits at any temperature/time combination, damage may be manifested as irregular ripening, initiation and/or aggravation of certain physiological disorders, development of off-flavors, and increased susceptibility to decay (Watkins, 2000).

Squash

Squash is a common name for American trailing plants of a genus of the gourd family. Squashes make up the genus *Cucurbita* of the family Cucurbitaceae. Summer squashes are varieties of the species classified as *Cucurbita pepo.* Squashes have been developed in many varieties and yield fruits of widely differing forms and sizes. Summer squash, including the summer crookneck, the white or yellow scallops, and the green zucchini, is harvested early, before the rind has begun to harden (Reynolds, 1998).

Summer squash (also known as vegetable or Italian marrow), is a tender vegetable that can be grown throughout a warm, frost-free season. Summer squash differs from fall and winter squash in that it is harvested before the rind hardens and the fruit matures. It grows on bush-type plants that do not spread like the plants of fall and winter squash and pumpkin. A few healthy and well-maintained plants produce abundant yields. Summer squash appears in many different fruit shapes and colors: Scallop or Patty Pan is round and flattened like a plate with scalloped edges, usually white but sometimes yellow or green. Constricted neck is thinner at the stem end than the blossom end, classified as either "crookneck" or "straightneck", depending on whether the stem end is straight or bent, and is usually yellow. Cylindrical to club-shaped Italian marrows, such as zucchini, cocozelle and caserta, are usually shades of green but may be yellow or nearly white. The varietal selection of summer squash has markedly changed in recent years and the number of varieties offered has greatly expanded as the result of new interest, hybridization, and introduction of disease resistance. Recommended varieties of summer squash include Zucchini (Open Pollinated): Black Zucchini (best known summer squash; greenish black skin, white flesh), Black Beauty (slender, with slight ridges, dark black-green), Cocozelle (dark green overlaid with light green stripes; long, very slender fruit), Vegetable Marrow White Bush (creamy greenish color, oblong shape), Zucchini (hybrid): Aristocrat (All America Selection winner; waxy; medium green), Chefini (AAS winner; glossy, medium dark green), Classic (medium green; compact, open bush), Elite (medium green; lustrous sheen; extra early; open plant), Embassy (medium green, few spines, high yield), President (dark green, light green flecks; upright plant), Spineless Beauty (medium dark green; spineless petioles), Golden Zucchini (hybrid): Gold Rush (AAS winner, deep gold color, superior fruit quality, a zucchini not a straightneck), Yellow Crookneck: Early Yellow Summer Crookneck (classic open-pollinated crookneck; curved neck; warted; heavy yields), Sundance (hybrid; early; bright yellow, smooth skin), Yellow Straightneck: Early Prolific Straightneck (standard open-pollinated straightneck, light cream color, attractive straight fruit), Goldbar (hybrid; golden yellow; upright, open plant), Scallop: White Bush Scallop (old favorite Patty Pan type, very pale green when immature, very tender), Peter Pan (hybrid, AAS winner, light green), Scallopini (hybrid, AAS winner), Sunburst (hybrid, bright yellow, green spot at the blossom end), Other: Butter Blossom (an open-pollinated variety selected for its large, firm male blossoms; fruit may be harvested like summer squash, but remove female blossoms for largest supply of male blossoms), Gourmet lobe (hybrid; globe-shaped; dark green, with light stripes; delicious), Sun Drops (hybrid, creamy yellow, unique oval shape, may be harvested as baby with blossoms attached) (Packer Fresh Trends, 2002).

Because summer squash develop very rapidly after pollination, they should be harvested when small and tender for best quality. Most elongated varieties are picked when they are 2 inches or less in diameter and 6 to 8 inches long. Summer squash is not allowed to become large, hard and seedy because they sap strength from the plant that could better be used to produce more young fruit. Squash grow rapidly; especially in hot weather and are usually ready to pick within 4 to 8 days after flowering. Because the fruits are harvested when still immature, they bruise and scratch easily. They should be handled with care and used immediately after picking (Packer Fresh Trends, 2002).

Because summer squash is immature, it is considerably lower in nutritional value than its winter counterparts. Generally, there is little variation in nutritional value between varieties. The peel is where many of the nutrients reside. Nutritional fact for1 cup sliced, raw zucchini is as follow: Calories 16, Protein 1.31 g, Carbohydrates 3.27 g, Dietary Fiber 1.36 g, Calcium 16.95, Potassium 280.24, Vitamin A 384 IU, Folate 24.93 mg (Reynolds, 1998).

Squash may be soon used as widely as celery, bell peppers and carrots in the fresh-cut industry. It is well-suited for processing, with steady supplies and a wide choice of varieties. Yellow squash and the green elongated type known as zucchini are the most recognizable varieties, and summer squash comes in all shapes. It can be ordered from producers by specific type, skin color, size, shape, and packaging. Moreover, summer squash, despite its name, can be found throughout the year by ordering from different regions in season. Yellow crookneck and medium-green zucchini are generally used in specialty cut produce. Multi-colored mixes of half moon slices are popular for stir fry industry, while sticks and wedges are being used extensively for salads. Orders for five-pound packages of sliced yellow squash are consistently strong throughout the year (Reynolds, 1998).

Choosing the right variety of squash is important for shelf life. For example Precocious yellow types are newer and were developed to help mask plant virus symptoms that can appear on the fruit. Precocious types develop a cream color in the fruit's flesh more quickly after cutting than conventional fruit. The flesh of both types is bright white after cutting, but after 3 to 5 days, the flesh of the Precocious yellow type begins to oxidize while that of conventional types remains bright white (Packer Fresh Trends, 2002).

Summer squash has an average shelf-life of 5 to 14 days when stored at 4-10 °C at 90 % relative humidity (Schoneweis and Smith, 2000). Zucchini squash storage is limited because it is highly perishable (Lorenz, 1951; Phillips, 1946) and chilling sensitive (Mencarelli et al., 1983). Storage of zucchini is of interest because it serves as a source of vitamins C and A (Watt and Merrill, 1978) and because it is grown throughout the world.

Some research has been done to extend shelf-life of zucchini squash. For example, using a 1% O_2 atmosphere at 2.5°C (Wang and Ji, 1989) or 5 % CO_2 at 5°C (Mencarelli, 1987) extended shelf-life of whole zucchini squash fruit by reducing chilling injury and subsequent decay. A 2 % O_2 at 10°C was reported to minimize development of off flavor, which was more pronounced when cooked (Mencarelli et al., 1983). Slices of zucchini squash may tolerate 1% O_2 atmosphere because they do not have a barrier to gases (Izumi et al., 1996). The distance for gas diffusion is less in slices than whole fruit, which would result in a smaller gradient of O_2 (Brecht, 1980; Weichmann, 1986).

Quality Evaluation of Fresh-Cut Vegetables and Fruits

Minimal processing of raw fruits and vegetables has two requirements. First, it is important to keep produce fresh without losing its quality. Second, the product should have a shelf-life sufficient to make its distribution feasible (Huxsoll and Bolin, 1989). The requirements for the quality and shelf-life of the fresh-cut fruits and vegetables are good quality raw materials (correct cultivar variety, correct cultivation, harvesting and storage conditions); strict hygiene and good manufacturing practices; use of hazard analysis and critical control points (HACCP) principles; low temperatures during processing; careful cleaning and/or washing before and after peeling, good quality water (sensory, microbiology, pH) for washing; use of mild additives in washing water for disinfection or the prevention of browning; gentle spin drying after washing; gentle peeling, cutting slicing, and/or shredding; correct packaging materials and packaging methods; and finally correct temperature and humidity during distribution and retailing (Ahvenainen et al., 1994).

Quality is a subjective term, and according to Kader and Mitcham (1995), quality of fresh-cut fruits and vegetables is presented as follows: factors including appearance (freshness, color, defects, and decay), texture (crispness, turgidity, firmness, toughness, and tissue integrity), flavor (taste and smell), nutritive value (vitamins A and C, minerals, and dietary fiber), and safety (absence of chemical residues and microbial contamination). These quality characteristics play an important role in the marketing of the product since they are directly evaluated by the consumer (Salunkhe et al., 1991).

Color is an important attribute that can be affected by processing of fresh-cut product and indicates maturity and ripeness (Shewfelt, 1990). Changes in color are related to enzymatic reactions generally due to the contact of enzyme-substrate after cell rupture, as is the case of browning and discoloration (Qi and Watada, 1997) and, in some cases, by dehydration of tissues (Tatsimu et al., 1991; Avena-Bustillos et al., 1994).

Juice leakage can be another important problem affecting the quality of fresh-cut produce. It promotes drying of the product, acquiring a dull appearance, and also results in juice accumulation at the bottom of the container, which, in addition to poor visual quality, may also support microbial growth (Kader and Mitcham, 1995).

Processing operations bring microorganisms present on the surface into contact with wounded tissues. Microbial spoilage may be increased at the cut surfaces due to infiltration and the release of nutrients supporting microbial growth (Reyes, 1996). The product is exposed to possible contamination with bacteria, yeasts, and molds. In fresh-cut vegetables, most of which fall into the low acid category (pH 5.8-6.0), the high humidity and the large number of cut surfaces can provide ideal conditions for the growth of microorganisms (Wilcox et al., 1994). Marchetti et al. (1992) found high initial counts for psychrotrophic bacteria and total mesophilic bacteria in commercial vegetable salad. *Pseudomonas* are responsible for the bacterial soft rot (Varoquaux and Wiley, 1994; Wilcox et al., 1994). The presence of food pathogens is of particular concern in fresh-cut product because they may be consumed without heat treatment. These organisms are *Clostridium sp., Listeria monocytegenes, Vibrio cholerae, Salmonella sp. Shigella sp., Escherichia coli, Bacillus cereus,* and *Hepatitis A* virus. Others isolated from fresh cut produce are *Yersinia enterolitica* and *Aeromonas sp.* Psychrotrophic pathogens in fresh-cut products are *L. monocytogenes, Aeromonas sp.,* and *Y. enterolitica* because they can grow at 0°C to 5°C (Nguyen and Carlin, 1994). Chlorinated water (100 ppm for 5 minutes) has been widely recommended for sanitation. There is no doubt about its effectiveness on *L. monocytogenes* (Beauchat and Brackett, 1990).

Most reviews of fresh and minimally processed fruits and vegetables report vitamin C content (Reyes, 1996). In broccoli florets, 20 % loss of vitamin C occurred in both conventional (air) and modified atmosphere packaging (2% O_2, 7% CO_2) after 4 weeks of storage at 1°C (Christie and Steer, 1993). However, MAP increased the retention of carotene and retarded the depletion of sucrose compared with air storage (Reyes, 1996). Loss of vitamin C in fresh-cut leafy vegetables can be significant during extended storage. The effects of minimal processing on nutritional quality need identification due to a variety of vitamins supplied by the vegetables and fruits (Reyes, 1996).

Since fresh-cuts have a large surface area without skin, they have the potential for losing a substantial amount of weight, particularly at higher temperatures where the water vapor pressure is high. In film packaged salads, the relative humidity would be expected to be high, but is not sufficient because wilted leaves are often observed with these products. Edible coating or proper packaging is helpful in attaining relative humidity close to 100%. Few reports have been published on films or coatings designed to reduce water loss and also accommodate gas exchange (Banks et al., 1993; Baldwin et al., 1995; Christie et al., 1995).

Rapid Methods for the Quality Evaluation of Fresh-cut Products

Electronic Nose

Flavors are very important in the quality of food. Two components of flavor perception are taste and aroma. Taste is the result of nonvolatile compounds that interact with sensors on the tongue by the formation of basic tastes of sweet, sour, salty and bitter. Many volatile compounds are responsible for the aroma of a food. They play an important role in flavor and contribute to the nature of a food, its product identity, and to consumer preferences between brands. There are also off flavors and taints, which arise because of biochemical or chemical changes, microbial growth, or contamination (Hodgins, 1997).

The three sensory systems in humans that are responsible for the sensation of flavor are gustation (sense of taste), olfaction (sense of smell), and trigeminal sense (responsive to irritant chemical species) (Gardner and Bartlett, 1994). The sense of smell arises from the stimulation of the human olfactory system by volatile compounds. These volatile compounds go into the nasal cavity and across the olfactory area or epithelium. The chemosensory receptors located at the surface of the olfactory hairs or cilia have receptor binding proteins (~1000) that will bind with the volatile compounds (Pearce, 1997). These receptor cells (~100 million) amplify the signal and transmit it to the brain by the means of the axons. The signal is processed and compared with previous knowledge, and the brain tries to define the odor (Clapham, 1996).

Humans can detect a minimum of 10,000 odors, but the number of identifiable odors is approximately 50 (Bartlett et al., 1997). The specific combination of complex mixtures of many odorous molecules having different concentrations culminates in the recognizable flavors or odors. Odor molecules are generally small (20-300 Daltons) and polar. They can be detected by humans below 1 ppb (Korel, 2000). A single molecule can have a distinct odor. However, natural smells or flavors are complex mixtures of chemical species and contain hundreds of constituents (Dodd et al., 1992). Human sensory evaluation has a number of limitations. Sensory panels are expensive and time consuming. Even when they are highly trained, they are subjective, prone to error, difficult to correlate among different people, and can be subject to fatigue (Giese, 2000). Classical analytical techniques, such as gas chromatography (GC) separate, quantify, and identify individual volatile chemicals but cannot tell if the component has an odor. These data are often difficult to correlate with sensory information. In contrast, the advantages of electronic noses include rapid, real time detection of volatiles, less preparation time, lower costs, and ability to conduct automated odor measurements (Giese, 2000).

Electronic nose technology started with an instrument developed by Moncrieff (1961) to detect odors. Several researchers studied the redox reactions of odorants at an electrode, and modulation of electrical conductivity by odorants in 1964-65. The concept of an electronic nose as a chemical sensor array system to classify odor was first presented by Persaud and Dodd (1982). The electronic nose has different names such as artificial nose, mechanical nose, odor-sensing system, sensor array system. It is an instrument consisting of an array of electronic chemical sensors with partial specificity, and an appropriate pattern recognition system capable of recognizing simple and complex odors (Gardner and Barlett,1994). The main components of an electronic nose are sample handling mechanisms, an array of chemical sensors, signal preprocessing and conditioning, and pattern recognition techniques. The electronic nose technology simulates the human olfactory process with fewer sensors, and it has software to analyze the responses. Each sensor represents a group of olfactory receptors and produces time-dependent electrical signals in response to an odor. Though the specifity of each sensor may be low, the combination of several specifity classes results in a very wide range of information. Any noise or sensor drift can be corrected using signal preprocessing techniques. Finally, the classification and memorization of odors in brain can be emulated by the use of pattern recognition in the electronic nose (Gardner and Bartlett, 1999).

Application of Electronic Nose in the Food Industry

Quality assessment in food production, inspection of food quality by odor, control of cooking, inspection of fish, monitoring the fermentation process, checking rancidity of oils, verifying if orange juice is natural, monitoring food and beverage odors, grading whiskey, inspection of beverage containers, checking plastic wrap for containment of onion odor, and automated flavor control are a few applications of electronic noses to food products (Giese, 2000). Electronic nose can be used to monitor food odors during critical stages of production to ensure that optimum processing conditions are being maintained, to monitor product deterioration during shelf life studies and during transport to retailers. This system is ideal for quick QC/QA checking (Hodgins, 1997).

In the dairy area, sensor arrays have been used to determine the role of fatty acids in the aroma profiles of Swiss cheese (Harper et al., 1996), to differentiate enzyme modified cheese slurries (Jin and Harper, 1996) and to detect the odor differences in milk due to microbial load, storage time, and sensory panel perception (Korel et al., 1999). The selective discrimination of different heat treated commercially available milk (pasteurized, UHT and sterilized) was provided with an array of four semiconductor sensors (Sberveglieri et al., 1998). Zondervan et al. (1999) described the use of an electronic nose to distinguish between intermediate products from a crucial heating step in the process. These results were set against the results of other analytical data such as GC-MS and sensory analysis (Zondervan et al., 1999). Korel (2000) tested an electronic nose for odor assessment of milk inoculated with *Pseudomonas fluorescens* and / or *Bacillus coagulans*, to correlate microbial loads and sensory results with electronic nose readings, and to attempt to predict the shelf life based on microbial loads of milk samples in an accelerated study.

Electronic nose was used for separation of ground raw and cooked samples of pork-beef mixtures according to composition and freshness (Turhan et al., 1998). An estimation of quality of ground meat stored in a polyethylene sheet and a good possibility of predicting storage time was done using electronic nose (Winsquist et al., 1993). Electronic nose was also used to monitor sausage fermentation. Sensory panel results were compared with the electronic nose sensor readings in the early stage of the process and on the final sausage (Eklöv et al., 1998).

In the seafood area, applications of the electronic nose have been done in differentiation of odors in shrimp on ice (Balaban and Luzuriaga, 1996), storage of tuna (Newman, 1998), and salmon (Luzuriaga and Balaban, 1999a) at different temperatures using conducting polymer sensors. Electronic nose was also used to determine storage time of fish (Di Natale et al., 1996). The odor of decomposition in raw and cooked shrimp was searched based on electronic nose readings, sensory evaluation, ammonia levels (Luzuriaga and Balaban, 1999b). Korel et al. (2001) measured the changes of odor, color, microbial load, and sensory attributes of fresh Tilapia fillets over time, treated with sodium lactate and stored at different temperatures. She also correlated electronic nose data with sensory evaluation and microbial results and tested whether combination of electronic nose sensor data and discrete color spectrum better discriminates the quality, compared to these data used separately.

In fruits and vegetable area, fresh squeezed orange juice (Bazemore at al., 1996) and volatiles of citrus juice (Hodgins, 1995; Hodgins and Simmonds, 1995) have been studied. Bazemore et al. (1997) reported that grape fruit juices of different cultivars were discriminated using metal oxide sensors. An ion-trap mass spectrometer based on electronic nose has been utilized to differentiate between grapefruit juices that differ only in the concentration of a single component, and the sensor was able to identify that component (Goodner and Rouseff, 2001). Maul et al. (1997) studied the ability of an electronic nose to nondestructively identify and classify intact tomato fruit exposed to different harvesting and postharvest handling treatments based on their volatile profiles. Maul et al. (1998) also explored the use of electronic nose volatile sensing technology as a nondestructive tool to screen ripe tomatoes harvested at immature green and mature green stages. Quantification of the flavor and aroma changes occurring in ripe-harvested tomatoes stored up to 12d at 5°C to 20°C using a trained, descriptive sensory panel, chemical composition assays, electronic nose, and GC profiles was studied by Maul et al. (2000). Sinesio et al. (2000) discussed the performances of an electronic nose based on metalloporphyrin-coated quartz microbalance sensors and of an experienced panel of seven humans in the evaluation of gases derived from degradation reactions in tomatoes. Young et al. (1999) determined the applicability of electronic nose, in terms of selectivity and sensitivity, for the measurement of aroma in apples with only small differences in sensory properties. The electronic nose has been used to determine harvest ripeness in cantaloupes (Benady et al., 1995), to monitor the ripeness of fruit (Brezmes et al., 2000) and to evaluate quality assessment of packed blueberries (Simon et al., 1996). Werlein and Watkinson (1997) compared the sensory quality of conventionally processed carrots, green beans, and potatoes using metal oxide sensors and sensory panels. Riva et al. (2001) determined an electronic nose's usefulness in measuring the shelf life of fresh cut vegetables. In this study, volatile changes in samples of "cicorino" and shredded carrots packaged with cling films were analyzed by an electronic nose equipped with 10 MOSFET and 5 MOS sensors. They also analyzed microbial spoilage and color. Pattern recognition software program was used to evaluate the sensor signals. The response of 5 sensor signals was used to classify the degree of freshness of both vegetables. The first principal component of PCA was correlated to microbial population in the samples and to their color index, showing that electronic nose is a suitable tool to study the storage life of these products (Riva et al., 2001).

Börjesson et al. (1996) used an electronic nose to classify grains, and therefore reduce the inspector's exposure to grains that can be contaminated with aflatoxin. Samples of oats, rye, and barley with different odors and wheat with different levels of ergosterol, fungal, and bacterial loads were analyzed (Jonsson et al., 1997). The odor of good, moldy, weakly, and strongly musty oats was predicted using artificial neural networks. The percentage of moldy barley or rye grains in the mixture was also indicated. There was a high degree of correlation between artificial neural network predictions, and measured ergosterol, fungal, and bacterial loads. Hoffman et al. (1997) used an electronic nose equipped with 4 metal oxide semiconducting sensors to follow the flavor generation during toasting of wheat bread, and to follow their degree of roasting. Ridgway et al. (1999) demonstrated that mite-infested and un-infested wheat was distinguished by electronic nose with an array of 14 conducting polymer sensors. Some work has been done to discriminate among coffee cultivars, coffee from different origins, and coffee aromas (Aishima, 1991; Tan et al., 1995; Delaure et al., 1996).

There is a great potential of using the electronic nose in worldwide quality control applications due to its rapid, real-time detection of volatiles, less preparation time, lower costs, and the ability to conduct automated odor measurements,.

Shortcomings of Electronic Nose

Individual sensors must have reproducible response to a given odor or chemical. A given sensor must be reproducible throughout its lifetime. This can cause a problem in the applications of electronic nose because of difficulties of multivariate calibration and the complex data set required to train the pattern recognition software. The problem with the reproducibility of response over time arises from drift in the sensitivity of the sensors and poisoning effects. Drift is a slow change in sensitivity and occurs with time. It can also be due to the effects of aging, slow morphological changes in the sensors and other long-term effects. Sensor poisoning arises when a sensor is exposed to a material which irreversibly binds to, or interacts with, the sensing material causing to a reduction or total loss of sensitivity. It is possible to avoid poisoning by carefully selecting the right type of sensor for the particular application. Unfortunately, there is no chemical sensor which cannot be poisoned (Korel, 2000; Luzuriaga, 1999). The response reproducibility between sensors of nominally the same type is another concern. It is desirable to replace a sensor without recalibration and retraining the system. It is possible to train one sensor array and to use this training set for any nominally identical array in other instruments at different locations if the sensors are sufficiently reproducible. The use of electronic nose technology will be widespread if data can be transferred from one electronic nose to another. Changes in temperature, humidity and flow rate are important in sensitivity.

The effects of changes in temperature and humidity on the sensor' baseline and on the magnitude of their responses are currently problems for portable electronic noses.

Several companies are developing and marketing electronic noses for the food industry. Portable low cost electronic noses are now commercially available. Cyrano Sciences released in the first quarter of 2000 a lightweight, portable electronic nose for use in the field. Rapid response time, and one-button operation are advantages. Standard easy replaceable or rechargeable batteries supply power. Housed in a robust, water-resistant case, this portable electronic nose is suitable to all environments. The sensors have been shown to respond to a wide range of organic compounds, bacteria, and natural products (Giese, 2000). Coffee aromas, volatile components from essential oils, odors in packing materials, quality of medium grain rice, the ripeness of bananas, apples, mangos, avocados, pineapples, melons, and variety of vegetables were studied. (Giese, 2000).

Computer Vision System

Color and appearance are one of the primary criteria for acceptance or rejection of a food. Color has an influence on our decision making process to select , purchase and /or eat different food products, especially produce and meats (Luzuriaga, 1999).

Color can be measured and described in physical terms. However, the actual color that we perceive is the result of a complex series of processes in the human visual system (Rosotti, 1983). Each color has a specific radiance intensity at each wavelength in the visible spectrum (Giorgianni and Madden, 1998). This representation is not intuitive to define the color of an object. Therefore, different color scales or systems have been developed over time to interpret color perception and to quantify color discrimination (Fortner and Meyer, 1997). Most color systems use the tristimulus values X, Y and Z adopted by the Committee Internationale d' Eclairage (CIE, International Commission on Illumination), and represented in the two dimensional graphs known as the 1931 CIE chromaticity diagram. XYZ, xyY, Hunter L*a*b*, or CIE L*a*b*, RGB, and Munsell are other important color systems (Hutchings, 1994).

Visual inspection, spectrophotometry and tristimulus colorimetry have been used to measure color in foods (Luzuriaga, 1999). Most color measurements of foods are based on the reflectance of light from the surface. Visual evaluation is simple and fast, and results in an immediate perception of the color and appearance of the food. Human perception of the color and appearance can change from person to person. It is difficult to quantify the amount or the intensity and to define the color in the food. With uniform surfaces and colors in food samples, spectrophotometers and tristimulus colorimeters are widely used to measure colors (Luzuriaga, 1999). The color measured by a colorimeter is described as a single value in the XYZ or L*a*b* color scales. However, a single value is not a good presentation of the actual colors present in the food sample with different colors and non-uniform surfaces. Food samples has been chopped and blended to obtain a uniform paste to measure the"average" color although in many cases this is not a good way to present color data because food can lose its original color and appearance (Luzuriaga, 1999).

Computer vision system can be an alternative for food color measurement. It consists of a computer, software, and a video camera to obtain an image of an object. The image is digitized by dividing in small elements or regions, called pixels. Each pixel has information on the levels of the three primary colors (red, blue and green RGB) for an image. Computer vision can provide a complete description of all the colors present in the sample and the amounts of each color. With this procedure, one can look at each individual pixel and obtain the color information, therefore, samples with different sizes, shapes, surface texture, and colors can be analyzed. The only restriction is the size of the light box where the samples are placed. Luzuriaga (1999) assembled the hardware necessary for a computer vision system, and developed a computer program to assess and quantify the color of foods with non-uniform colors and surfaces in the RGB, L*a*b*, XYZ or Munsell color system. The hardware consisted of a light box, color video camera, frame grabber and computer. He also developed a color analysis software in Microsoft Visual Basic Professional (version 6.00 Microsoft Inc. Redmond, WA). It required dynamic link libraries (DLL) from Matrox Imaging Library (Ver. 5. 0, Matrox Image Processing Group, Quebec, Canada), Color Science Library (Ver. 2.0, Computer Graphic Systems Development Corporation, Mountain View, CA), Graphic Server (Ver. 5.10, Bits Per Second Ltd, Brighton, England) and Formula One (Ver. 4.1, Visual Components, Lexena, KS).

Applications of Computer Vision

Computer vision has seen a steep increase recently for quality evaluation and inspection (Krutz and Precetti, 1991; Okamura et al., 1993; Liao et al., 1994; Luzuriaga et al., 1997; Miller and Drouillard, 1997; Carderelli et al., 1998), grading (Miller and Delwiche, 1988; Diehl et al., 1990; Guedalia, 1997; Heinemann et al., 1997), and automatic fruit and vegetable harvesting (Sites and Delwiche, 1988; Miller, 1987). Computer vision has been widely used to automate quality evaluation. An automated peanut maturity detection system was developed by Ghate et al. (1993). Gunasekaran et al. (1988) detected soybean seed coat and cotyledon cracks by image processing.

Okamura et al. (1993) developed a computer vision system to grade raisins. Image processing algorithms for apple defect detection (Rehkugler and Throop, 1989), grading asparagus (Rigney et al., 1992) and peaches (Miller and Delwiche, 1988) with computer vision, a computer vision system capable of separating fresh market tomatoes based on visual quality (Sarkar and Wolfe, 1984), an online system to analyze the color, shape and blemishes of citrus (Miller and Drouillard, 1997) and a high resolution machine vision system for non-destructive internal inspection and classification of rough rice (Cardarelli et al., 1998) were developed. Pearson and Schatzki(1998) reported a machine vision system developed for automated detection of aflatoxin-contaminated pistachios. A computer vision system for characterizing corn growth and development (Tarbell and Reid, 1991), grading of mushrooms using machine vision system (Heinamann et al. 1994) and computer-vision-based system for plant growth analysis (Shimizu and Heins, 1995) were also studied. In baking food area, McConnell and Blau (1995) studied color classification of non-uniform baked and roasted foods.

Hatano et al. (1989) used digital image processing to find an objective creation to predict the flesh redness from the spawning coloration of fall chum salmon. Geometric and physical properties of oyster meat was described by computer vision (Diehl et al., 1990). A method to detect oyster hinge line was presented by computer vision (Li, 1990). A book was published about fish quality control by computer vision, covering parasite detection, length measurements, fish inspection and sorting etc. was published by Pau and Olafsson (1991). Fish species were recognized and their size calculated by image analysis from their shape (Strachan et al., 1990). An adaptive threshold technique for shrimp images (Ling et al., 1988) and a feature extraction system for a vision based shrimp deheader (Ling and Searccy, 1989) were developed. Kassler et al. (1993) developed a prototype for automatically grading and packing prawns into single-layer consumer packs, in which each prawn is approximately straight and has the same orientation; this system combines computer vision and robotics. Balaban et al. (1994) evaluated the count and uniformity ratio of tiger and white shrimp. From the correlation of weight to view area of individual shrimp, count was estimated, and it was concluded that the weight of individual shrimp can be accurately determined by computer vision. Luzuriaga et al.(1997) developed a system to grade melanosis and to measure color of white shrimp. He also did quality evaluation study by automating and correlating color and odor of salmon. Newman (1998) used a computer vision system to evaluate the color of raw tuna stored at different temperatures. Korel et al. (2001 a, b) combined discrete color spectrum data and electronic nose sensor readings analyzed with Discriminant Function Analysis to have better overall evaluation of product quality for catfish and raw tilapia. They measured the odor, color and several quality changes such as microbial load, pH, water activity, and moisture content in catfish fillets during refrigerated storage. Electronic nose readings and color machine vision system results were correlated with sensory evaluation in raw and cooked fillets, and with sensory evaluation and microbial loads in raw fillets. They also measured the changes in odor, color, microbial load, and sensory attributes of fresh Tilapia fillets over time, treated with sodium lactate and stored at different temperatures by correlating electronic nose data with sensory evaluation and microbial results and analyzing the color data by histogram and Discriminant Function Analysis methods. They tested whether the combination of electronic nose sensor data and discrete color spectrum better discriminates the quality, compared to these data used separately.

Texture Evaluation

Texture is related to the physical characteristics that are experienced by biting and chewing. Textural characteristics of product, the degree of each of these characteristics present and the order of their appearance during the mastication process is determined (Brady et al., 1985). Texture is a multi point property of foods (Bourne, 1978). Food texture is defined as the properties which arise from structural elements, and the way they register with physiological senses (Brady and Hunecke, 1985). Therefore, texture is the result of the structure of the food, it is a composite of several properties, and it is a sensory attribute.

Toughness is a critical factor in raw vegetables. Vegetable toughness is a complex property which relies on pectic structure. In modified atmosphere storage, time, temperature, and plastic films have strong influence on the final toughness as well as other quality factors such as color and taste. A high quality zucchini should not have a soft texture or a mushy, slimy feel. Both characteristics are indications of enzymatic or microbial deterioration (Gorga and Ronsivalli, 1988).

Methods of Texture Measurement

There are two ways to determine complex food texture either by instrument or by sensory evaluation. Sensory evaluation is more valuable in the measurement of food texture since no available instrument can detect, analyze and integrate a large number of textural sensations at the same time (Larmond, 1976). However, it may not be repeatable. Therefore, correlation of repeatable instrumental methods to sensory data is essential.

Generally, relationships between sensory and instrumental texture profile parameters, or those among sensory or instrumental values are examined (Beilken et al., 1991; Chen and Trout, 1991; Chung and Meritt; 1991; Meullenett et al., 1994; Reid and Durance, 1992; Troutt et al., 1992). Most researchers compare their instrumental measurements with sensory results. Otherwise, instrumental textural evaluation would be of little practical value. However, sensory evaluations have methodological, physiological and psychological variations. In addition, they are expensive and time consuming (Ahmed et al., 1973; Beilken et al., 1991, Brady and Hunecke, 1985; Chung and Meritt, 1991; Meullenet et al., 1994; Reid and Durance, 1992). Texture Profile Analysis (TPA) and shear tests are mostly used for textural evaluation of fruit and vegetables. TPA interprets the force deformation curves obtained by an Instron to evaluate seven textural parameters, five measured and two calculated, from the measured parameters (Bourne, 1978; Breene, 1975; Peleg, 1976). These are fracturability, hardness, cohesiveness, adhesiveness, springiness, gummines, chewines. A shear test is used to cut a piece of material and determine the force it takes for the blade to do work. Several researchers related the shear force with hardness and chewiness (Ahmed et al., 1972; Ma et al., 1983; Webb et al., 1975). When a recording type of instrument is used, both maximum force readings and areas under the curve can be determined. Generally the former is used since it is easier to determine and since no definite advantages of area measurements have been demonstrated.

All shearing devices are subject to error caused by differences in sharpness of the blades, alignment, warpness, etc. Difficulties in standardizing the entire unit, including the cell is still a problem (Szczesniak, 1972). Cutting devices employ a knife-like blade to cut through the sample. They have been used mainly to test meat, cheese, and vegetables such as asparagus, tomatoes, pineapples etc. (Szczesniak, 1972).

Application of Shear Test

Chung and Merritt (1991) developed an instrumental method of texture measurement for scallop meat after frozen storage to replace the sensory method. They measured Instron compressive and shear forces as substitutes for sensory evaluation. A thirteen member trained sensory panel was used to evaluate the samples by rating their tenderness and toughness and comparing them to reference samples. In instrumental method, a peak compression force with 50mm/min load cell speed, 15 mm plunger diameter, different compression levels (30% (F=1kg), 50% (F=2kg), 80% (F=10kg)) with different force values and a shear peak force and slope (measured with a single Warner Bratzler Shear device with a speed of 50mm/min (F= 1kg)) methods were used in an Instron. They found that the most convenient instrumental method was compression to 50%, which gave a correlation of 0.89 for 12 samples assessed by both sensory and instrumental techniques.

The Warner-Bratzler shear and Instron compression and extension for sensitivity to the textural changes caused by heating scallop adductor muscle were studied by Findlay and Stanley (1984). In instrumental tests, they used 2 kg load cell, 50% compression and 100mm/min cross head and chart speeds. Hardness was selected since it gave the greatest slope with respect to temperature. Scallops were heated to internal temperatures of 25 to 80°C. A linear increase in hardness between 25 and 60°C was found, causing water loss. Hardness continued to increase after 65°C with a slower rate. A large weight loss between 40-50°C occurred, and another sharp increase between 55-

60°C which leveled off at 45% above 70°C. A linear equation was found to fit over the temperature range examined. Weight loss was affected by holding time (range 7-10 min) since higher internal temperatures required longer equilibration time. The linear model between weight loss and temperature gave a significant correlation with hardness ($r^2>0.90$).

Erdoğdu (1996) measured the changes in textural attributes of shrimp in different sizes by cooking at isothermal and transient temperatures, and also tried to find correlations between instrumental texture measurements and sensory properties. Texture measurements and sensory tests were performed on different sizes of shrimp cooked in different temperatures. In this study, TPA and shear test were performed using a Instron Universal testing machine. Tenderness, juiciness, rubberiness, and overall acceptability were determined by sensory panels and correlated with instrumental results. Temperature significantly affected all textural properties and sensory attributes. High correlations were obtained between textural properties and sensory attributes by Erdoğdu (1996).

Berrang et al., (1990) studied textural qualities of fresh asparagus, broccoli and cauliflower stored under controlled atmosphere. They measured firmness by determining the energy (Joules/mm^2) needed to shear each vegetable using an Instron. A Warner Bratzler blunt blade apparatus and a cross head speed of 50mm/min was used. Asparagus was sheared in cross section at about 1/3 the distance from tip to base of the stalk. The stem of broccoli was sheared in cross section directly below the floret head. Cauliflower was sheared through the stem in cross section at the base of the floret head. Asparagus stored under CA was easier to shear than asparagus stored under air ($p\leq 0.05$). Asparagus stored under air developed a distinct soft slimy outer layer by day 14.

Therefore they suggested shear force values may not be a reliable indicator of quality in this case. Broccoli stored under both atmospheres remained relatively firm throughout storage. CA had no significant affect on the texture of broccoli stems and texture of cauliflower ($p \leq 0.05$).

Raw jicama tubers, Chinese water chestnut corms and white potato were tested for texture by Mudahar and Jen (1991). First and second bite compression curves for each vegetable were developed using Instron. Dices were put breadth-wise between two parallel stainless steel plates. Instron settings were cross head speed 50mm/min; chart speed 200mm/min and deformation 70%. Crispness was measured as the first significant break in the first positive area as defined by Szczesniak (1972) as fracturability. Chinese water chestnut required relatively less force for fracture, followed by a series of small peaks as it was fractured into small pieces and finally was crushed at maximum compression. Raw jicama had moderate hardness. Raw white potato showed a steep initial slope and had most fracturability and hardness among the three (Mudahar and Jen, 1991).

Quality Evaluation of Zucchini Squash

Mencarelli et al. (1983) tested responses of zucchini to storage in low O_2 atmospheres at chilling and nonchilling temperatures. They stored zucchini 2 weeks at 2.5, 5, and 10˚C and with 1, 2, 4, 8 or21% O_2, and then they aerated them 2 days at 10˚C. Then they stored the squash in glass respiration jars, and performed gas analysis as well as overall quality, color, low O_2 decaying and firmness subjective evaluation. They also measured off-odors and flavors of cooked zucchini. They cooked them halved lengthwise, placing into 3 liters of 1% NaCl water for 4 min after it reached 95˚C. Once pieces were cooled to room temperature, they measured shear with an Instron equipped with a 6.3 mm diameter circular probe. The cross-head and chart speeds were 30 and 100 mm/min, respectively. Full scale force was 19.6N. The direction of travel for the probe was from the center to skin. Travel in the opposite side tended to reflect skin texture rather than shear resistance of the flesh. They concluded that storage at 5˚C induced chilling injury and permitted minimal development of surface mold, decay, or off-flavors during two weeks of storage After 2 weeks squashes looked good at 5˚C. A distinct, musty off-odor affected all raw samples from 10˚C, regardless of O_2 concentration. Strong, highly objectionable "bitter" off-odors developed during cooking in squash held at 2.5˚C with 1% O_2 or 10˚C in air or 1% O_2. In raw squashes, severe off-flavor and bitterness were confined to samples held at 10˚C in air or in 8% O_2 at 2.5˚C. Some samples developed sweet flavor. In cooked samples, bitterness was common in zucchini held at 10˚C. For cooked samples, storage at 5˚C was best and O_2 levels below 8% provided little benefit. In contrast, 10˚C storage in 2% O_2 helped retain flavor better than higher or lower O_2 concentrations. The resistance to penetration of the cooked tissue was not influenced by the experimental variables, except the samples held 10˚C had a slight tendency to soften during storage. The initial resistance to penetration ranged from 7.3 to 15.0N. They mentioned that the large variation in resistance of the squash to penetration is the result of nonhomogeneous structure of the fruit The location of the vascular tissue and the seeds influence the penetration force. The attainment of precise information on the texture of the mesocarp would require removal of the seeds and associated tissue before testing. However, since the entire squash is eaten, information on the mesocarp may not reflect human perception of the texture. Evaluation of the firmness of the raw squash by hand pressure also revealed no consistent differences among various treatments (Mencarelli et al., 1983).

A similar study by Mencarelli (1987) tested the effect of high CO_2 atmospheres on stored zucchini squash. He stored them for 19 days at 5˚C in 21% ± 1% O_2 plus 0%, 2.5% 5%, or 10% CO_2 and then stored an additional 4 days at 13˚C in air. Squashes were separated into 3 length classes (16, 20, 22cm). They were split lengthwise. Firmness was measured by pushing the tip from the center toward skin, and elasticity was measured as the resistance of fruits to bending using a penetrometer. They evaluated overall quality subjectively on a rating scale, presence of off-odor, off-flavor, pH and weight loss tests. At the end of 23 days of storage, 82% of 22cm squash held in 10% CO_2 appeared salable but they had slight off flavor and softness. 79% of the squash stored in 5%CO_2 were saleable, firm, and free off flavors. Samples from 2.5%CO_2 and air were unacceptable because of decay and pitting. They concluded that 5%CO_2 may be useful for storing zucchini squash at about 5˚C that normally causes chilling injury in zucchini.

Izumi and Watada (1995) studied calcium treatment to maintain quality of zucchini squash slices by dipping in solutions of $CaCl_2$ alone or with chlorine, and stored at 0,5, and 10˚C. Three replicates of each treatment were stored at 0˚C, 5˚C and 10˚C for 17, 16, 12 days. Their appearance, texture based on shear force, microbial count and surface color of slices were tested. Slices developed water soaked areas (chilling injury) at 0˚C and brown discoloration at 5˚C and 10˚C which increased with storage. The severity of chilling injury/browning/decay of water dipped controls were least at 5˚C. Calcium treatments helped in reducing development of decay, rate of total microbial growth, ascorbic acid loss, and shear force decrease of slices stored at 0°C and 10°C, but not 5°C.

Similar studies with low O_2 atmospheres affected storage quality of zucchini squash slices treated with calcium (Izumi et al., 1996). Calcium treated and non-treated zucchini squash slices were stored in air or low O_2 (0.25, 0.5, and 1%) at 10°C for 10 days. Their respiration rate, ethylene production, evaluation of browning/decay and off-flavor, L-ascorbic acid, texture based on shear force for a 40g sample, total microbial count, pH, and color were measured. Respiration rate, ethylene production, and development of browning/decay were decreased under low O_2. Slices held in 0.25% O_2 had less weight loss and browning/decay, and greater shear force and ascorbic acid content than those stored in air. Microbial count, pH, and color were improved by low O_2 at the end of the storage.

Objectives

The main goal of this work is to objectively measure the quality of modified atmosphere stored sliced zucchini squash using an electronic nose, machine vision system and Instron. Sensory panel results and microbial counts will be correlated with electronic nose machine vision and Instron evaluations. The specific objectives are as follows:

1. To subject sliced zucchini squash to different modified atmosphere conditions, and store these samples at a constant temperature until beginning of decay.
2. To measure, at pre-determined time intervals, organoleptic quality parameters (appearance, odor, texture etc.) of these samples, as well as their microbial numbers (total aerobic plate count).

3. To measure, at the same time intervals, objective quality parameters using Neotronics electronic-nose, machine vision system and Instron.
4. To evaluate and statistically correlate the relationship between organoleptic evaluations and objective readings.

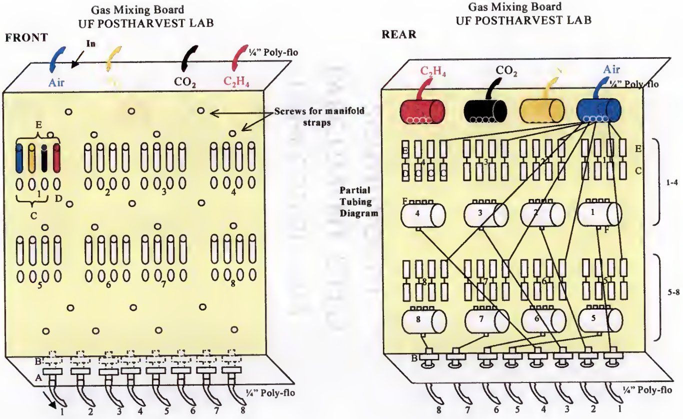
CHAPTER 3
MATERIALS AND METHODS

Controlled Atmosphere Study

General Preparation

One week before the experiment, the gas mixing system was prepared for controlled atmosphere storage. It consisted of the mixing board (Figure 3-1)and three flow boards (Figure3-2) (Fifield Hall, Horticultural Sciences Department, University of Florida, Gainesville, FL) used to provide accurate flow rates of air and gas mixtures to the samples at desired rates. The system also allows a regulated modification of gas mixes for measurement of respiratory rates. The gas mixing system is based on the principle that final composition can be set by gas flow rates, for gases of equal pressure. The pressure levels of air, CO_2 and N_2 are set with pressure regulators. The gas mixing board consists of distribution manifolds, on-off valves, needle-valve flow meters, mixing manifolds, and associated tubing and connectors. The on-off valves are color coded for various gases.

In our controlled atmosphere (CA) study, the flow rate of each individual gas in two kinds of mixtures was calculated (shown in appendix A). The total flow rate (267ml/min for 10 containers) was chosen based on the amount of product (200g) and its respiration rate (calculation shown in appendix A) (39ml CO_2/kg-hr) so that respiratory CO_2 buildup was minimized (usually< 0.5%). Each gas flow rate was set individually by



(Not to scale)

Out

*A= Outlet from mixing board to bubble through water
*B= Distribution manifold
*C= Gas pressure regulators

(Not to scale)

*D=mixing manifolds
*E= on-off valves
*F= Tubing's and connectors

Figure 3-1. Gas mixing board located in Postharvest Laboratory, Horticulture Department, University of Florida, Gainesville, FL.

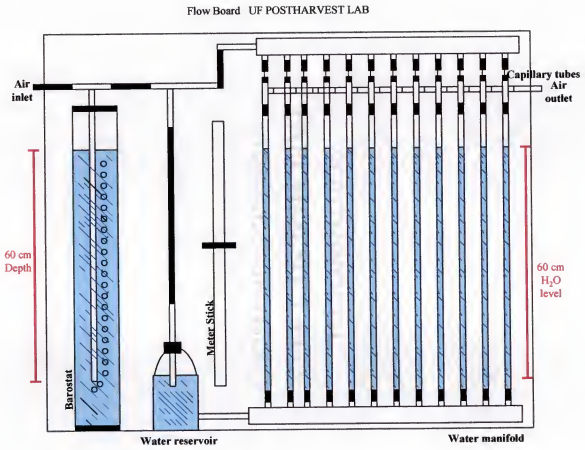


Figure 3-2. Flow board located in Postharvest laboratory, Horticulture Department, University of Florida, Gainesville, FL.

opening the on-off valve and adjusting the flow rate with needle valve-measuring the flow rate with a bubble flow meter.

When all of the component gas flow rates were set, all necessary on-off valves were opened and the mixture verified by GC. The next step was to humidify the gas mixture by bubbling it through water. The flow boards were used to split the gas flow from the mixing boards to send it up to 12 replicate chambers. The flow boards used a barostat and manometer tubes to adjust and maintain uniform gas pressure, and capillary tubes (Corning Inc., Corning, New York) to control the flow rates. Changing the depth of the tube in the barostat changes the height of the water in the manometer tubes and flow rates change proportionally. The height of the water in the manometer tubes is usually set at 60 cm-measured from the meniscus in the tube to the top of the water reservoir bottle. When using the flow boards we checked that each outlet had either a capillary tube in line or a solid glass plug. The bubbling in the barostat had to be slow to minimize water evaporation in the barostat. The 60 cm adjustments had to be checked daily as the water level changed and sometimes the air pressure could change.

The recommended gas compositions for fresh-cut zucchini squash stored in cold temperatures is 1- 4% O_2 and 5% CO_2 at 8-10°C for controlled atmosphere (CA) (Kader, 1992) and 2-7% O_2 and 5-8% CO_2 at 5°C for modified atmosphere (MA) (Park and Cho, 1999). In the CA experiment, two different gas combinations (2% O_2+7% CO_2 balance N_2 and 2% O_2+15% CO_2 balance N_2) were selected from the literature, and air (21% O_2) was used to test whether these gas combinations were suitable for zucchini squash slices.

Determination of Respiration Rates for Mixing System

Respiration measurements are often limited to CO_2 production because of simplicity. In this experiment, a static system (Figure 3-3) was used to determine respiration rates by placing the sample in a closed system. Sample weight (kg), volume of free space in the container (assume the sample occupies 1ml/gm fresh weight), and residence time were determined. Using GC, the increase in CO_2 during a fixed period of time was measured by drawing gas samples from the chamber.

Calculation was done in three replicates using Equation 1.

$$\mathbf{RR = \%CO_2 \times V / (M \times t \times 100)} \qquad (1)$$

where % CO_2 (in the headspace readings from GC) was the concentration in the jar during the measuring period, V (ml) was the volume of free space of the jar, M (kg) was the mass of the product in the jar, t (hr) was the time during which CO_2 accumulated in the jar; RR (ml CO_2 /kg-hr) was the respiration measurement. Calculation is shown Appendix A.

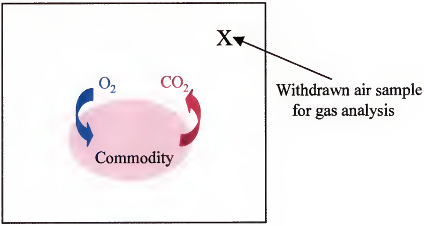


Figure 3-3. A static system.

Known amounts of hand-sliced zucchini squash were placed into glass Mason jars (1892.5 ml, Duval Container Co., Jacksonville, FL) with known void volume, and hermetically sealed with tin-plate twist-off lids (120 mm, Cat no: 330150 Duval Container Co., Jacksonville, FL). The lids were fitted with brass tubes with stoppers for gas sampling. Brass tubes were sealed with 2 septa. After a known period of time at a predetermined temperature, 0.5 ml gas samples were withdrawn from headspace using a 1 ml BD gas-tight plastic syringe inserted through the septum on the jar lid. Two replicates from each treatment were measured. The concentration of CO_2 generated by product respiration accumulated inside each jar was measured using GOWMAC, series 580 GC, with a thermal conductivity detector and a Hewlett Packard Model 3390A integrator. Carrier gas was Helium at 40 psi with an adjusted 30-ml/min flow rate. The column was Propak Q 80/100 Mesh, Molecular Sieve 5A 80/100 Mesh and CTR-1. Column temperature was 40°C. Detector and injector temperatures were 28°C. Detector current was 90mA. Calibration of GC was done before any sample analysis using a certified standard mixture (Spec connection International Inc. Analytical Laboratories, Lutz, FL).

Determination of Flow Rates for Mixing System

The total flow rate was determined by the expected rate of CO_2 production of the sample (USDA handbook #66, and also respiration rate calculation). Flow rates were set so as to guard against high CO_2 effects. The flow rate (ml/min) needed to keep the CO_2 concentration below a certain level, eg. 0.5% given by:

$$\text{Total flow rate (ml/min)} = \text{Respiration rate (ml } CO_2 / \text{kg-hr)} / 0.005 \times 60 \text{ min/hr}$$

$$\text{For 1 kg } (0.005 = \% \, CO_2 / 100)$$

The desired gas mixtures were obtained by mixing appropriate amounts of air, CO_2, and N_2. All gases were maintained at a constant pressure differential using the pressure gauges on the mixing board. The individual flow rates were determined using the following procedure:

Component gas (%) x Total Flow (ml/min) / Gas Source (%)

For controlled atmosphereexperiment:

Total flow rate for each container: 27 ml/min

Individual flow rate for the composition of 2% O_2 + 7% CO_2 (balance N_2) were 25.53ml/min, 18.62 ml/min and 221.84 ml/min, respectively. Calculation was shown in Appendix A. Individual flow rate for the composition of 2% O_2 + 15% CO_2 balance N_2 were 25.53 ml/min, 40 ml/min and 251.08 ml/min, respectively (Appendix A).

Flow rates were set using the appropriate flow meter on the mixing board. Flow rate for each gas were adjusted using a hand held flow meter (ADM 1000 Intelligent flowmeter, Flowmeter J&W Scientific Co., Folsom, CA) for flow rates not greater than 1000 ml/min.

Processing Room and Cold Room For Storage

The day before the experiment, both cold room for storage and minimal process rooms were cleaned and sterilized. Their temperatures were set at 10°C and 5°C, respectively, and stabilized for one week and checked every day. Their relative humidity was set to 95% and monitored by hand-held Durotherm-Hygrometer (Model no: R560, Abbeon Cal Inc., Santa Barbara, CA).

Containers and Utensils

Plastic containers (Fridge Smart Tupperware® ,1701-16, Impression Classic Bowl Set, Orlando, FL) containing two shelves prepared from plastic wire mesh (1" hardware cloth, Home Depot, Gainesville, FL) and each utensil such as salad spinner, hand slicer, knives etc. used in this experiment were cleaned and sterilized swabbing with ethyl alcohol (95%, Cat. No. 0109, Health Center Stores, University of Florida, Gainesville, FL) and stored at 5˚C for a night.

Cleaning Water

Cleaning water to wash zucchini squash were prepared by pouring 58 mL of a concentrated solution of sodium hypochlorite (6% w/v) into 15.1L of distilled water, and pH was adjusted to 7.0 with 1:1 ratio of HCl solution (Cat. No. BP152, LotNL9409140, Fisher Scientific Co., LLC, Suwanee, GA) and distilled water. Cleaning water was prepared the day before experiment, and stored in polyethylene bottles with tight-fitting lids at 5˚C.

Minimal Processing

In the CA study, small zucchini squashes (*Cucurbita pepo L. cv.* Elite) were purchased from Publix grocery store in Gainesville, Florida on May 26th, 2000. They were harvested from Kindel Farms, Beverly, FL. They were picked, washed, separated according to size and shipped to Gainesville on May 25th, 2000. Squashes were already packed in polystyrene trays (27x15.5x4cm) wrapped in polyvinyl chloride (PVC) shrink film. They were stored at 10˚C with 95% RH for one night in Postharvest laboratory, Fifield Hall, Horticulture Science Department, University of Florida, Gainesville, FL.

The day of the experiment, zucchini squashes were randomly sorted by size and visual appearance and sanitized by immersing whole zucchini squashes in cleaning water for 2 min. Then, they were sliced (5-6 mm thick, 5-6g each) using Feemster's Famous Vegetable Hand Slicer (Jensco, Inc., East Glastonbury, CT) after trimming 2cm from both blossom and stem ends with a sharp knife. Slices were spin-dried using a salad spinner (Space Saver, BS-101, Bentoville, Arizona) for 2 min to remove excess water, and they were placed single layer on two shelves of the container (~200g/per container). The plastic containers (180 mm in diameter and 110 mm in height) were surrounded by Parafilm (Parafilm ® "M", Laboratory Film, American Can Company, Greenwich, CT,) to provide tight-fitting with lids. A 40 mm-long brass tube (Nalgene®, Fisher Scientific Co., Suwanee, GA) fitted with stoppers for gas sampling and semi-rigid tubes (Dayco® Imperial poly- flo® 33-PE-3/16-NSF, Fisher Scientific, Orlando, FL) to feed gas mixtures were inserted through the lids. Then, containers were sealed with these lids and wrapped by parafilm. Then, the containers were placed in a walk-in cold room (10˚C, RH=95%). Ten plastic containers for each gas combination were attached to the CA gas mixing system. Estimated equilibration was reached in the time required for 4-6 container volumes of gas to pass through the system. The gas flow was humidified by bubbling it through water before introducing it into the containers. Gas compositions in CA were monitored daily using Servomex O_2 and CO_2 analyzer (Servomex, Norwood, MA). The analyzer was calibrated using N_2 and a certified O_2 and CO_2 standard every day before measurement. Flow rates of N_2, CO_2 and air during storage were controlled by a ADM 1000 Intelligent flow meter (Flow meter J&W Scientific Comp., Folsom, CA).

Respiration Measurement

The respiration rate of sliced zucchini squashes over time were determined for CA experiment, experiment I, and experiment II. Data showed similar trend for gas measurements. Thus, data was not presented in here, however it can be obtained from Dr. Murat Balaban, Food Science and Human Nutrition Department at the University of Florida, filename: \\thesis\text files\ chap 3\ zucchini respiration rate data.txt.

Comparison of Gas Chromatography and Headspace Analyzer

During CA experiments, GC gave unreliable results even when it was calibrated just before measurements. First, it was thought that syringes used for injecting samples to GC was the problem. Instead of using 1.0 ml BD plastic syringes, 1ml glass syringes were used but results did not improve. After every 10 injections, the septum in the injection port was changed, however results were still different between replications. It was decided to try another gas analyzer. PBI Checkmate 9900 O_2/CO_2 headspace analyzer (Topac Inc., Hingham, MA) was used to measure oxygen and carbon dioxide levels. The instrument works by drawing a small sample (1-2 ml) of the headspace gas into a ceramic/zirconium detector for oxygen and Infrared detector for carbon dioxide. The analysis is very quick and results are displayed on an LCD display within a few seconds. It is very sensitive, and it measures oxygen from 0.001% to 100% and carbon dioxide 0-100%. Results are printed using the built-in printer. Carbon dioxide and oxygen in CA or MA system can be measured by taking samples from the headspace by piercing with a special gas tight syringe, which contains a 0.8mm sterile needle (Terumo® 21Gx11/2 0.8x40 Nr. 2,Cat no: 920012, Topac Inc, Hingham, MA), 5 µm needle filter (Cat no: 970179,Topac Inc., Hingham, MA), needle pan (Cat no:

970169,Topac Inc., Hingham, MA), O-rings (Cat no: 920095,Topac Inc., Hingham, MA), and finger screws (Cat no: 900348,Topac Inc., Hingham, MA), through a septum (Cat no: 940296 ,Topac Inc., Hingham, MA) placed on the bags. Gas concentrations (%) are displayed on the LCD screen. Using the enclosed septa ensures that measurements were not affected by leaks occurring from penetration of the needle through the packaging film. The septum kept the package airtight. The unit is fast to warm up, and has a fast response time (50ms).

An experiment was performed with three different bags supplied from Ready-Cut Inc. (Chicago, Illinois) having zucchini samples, and empty bags. Their dimensions and permeabilities were different (Table 3-1).

Table 3-1. Gas permeability rates of the plastic bags used for comparison of gas chromatography and headspace analyzer experiment.

Experiments	Plastic bags	Transmission rates (mmoles x m)/(m^2 day atm)							
		CO_2				O_2			
		Rep1	Rep 2	Avg	Std	Rep 1	Rep 2	Avg	Std
GC vs Head Space Analyzer	Plastic bag 1	0.0353	0.0326	0.0340	0.0019	0.0057	0.0054	0.0056	0.0002
	Plastic bag 2	0.0261	0.0265	0.0263	0.0003	0.0041	0.0043	0.0042	0.0001
	Plastic bag 3	0.0167	0.0156	0.0162	0.0008	0.0031	0.0030	0.0031	0.0001

In this experiment, whole zucchini squash (*Cucurbita pepo L. cv.* Elite) purchased form a grocery store in Gainesville, FL were first washed with chlorinated water, sliced, washed for 2 minutes and spun in a salad spinner for 2 minutes, then placed into the plastic bags followed by vacuuming and flushing with 2% O_2 +15%CO_2 balance N_2 gas mixture using PAC Vacuum Impulse Heat Sealer (San Rafael, CA). 20 g NaCl as desiccant and a Relative Humidity (%) Logger (StowAway® RH Relative Humidity Logger, Onset Computer Corperation, Bourne, MA) were also placed in the bags before vacuuming to monitor RH (%) changes during storage. Three different arrangement inside the bags were provided: plastic bag with zucchini slices (~ 280 g), desiccant and RH logger, plastic bags with just zucchini slices, and plastic bag with no sample. All treatments were done in 2 replications, and three gas readings at every time interval were performed. Average results were presented in Table 3-2. Results followed an expected trend in Headspace Analyzer with no deviation between readings. However, GC readings had large deviations between readings. Although a MA of 15% CO_2 and 2%O_2 was expected as soon as bags with no sample were sealed, readings from GC ranged from 7 to 8% for CO_2 and 5 to 7 % for O_2 inside the bags (Table 3-2). However, readings from headspace analyzer were 15% for CO_2 and 2% for O_2 inside the bags. Decrease in CO_2 and increase in O_2 could not be seen clearly using GC method. Therefore, it was decided to use headspace analyzer for gas analysis.

Quality Evaluations During Storage

Samples were stored up to12 days. Two plastic containers from each treatment were severed from the gas mixing system and transported in coolers from Fifield Hall, Horticulture Department, Gainesville, FL to Food Science and Human Nutrition Department, Gainesville, FL. They were evaluated every other day for changes in objective quality parameters such as odor, color, texture etc. using electronic nose, machine vision and Instron as well as organoleptic quality parameters using 8 panelists. Aerobic microbial count were also performed using 3M petri film.

Table 3-2. Comparison between head space analyzer and gas chromatograph.

Time		HEADSPACE ANALYZER																	
		Treatment 1						Treatment 2						Treatment 3					
		Plastic bags with zucchini slices and dessicant						Plastic bags with zucchini slices						Plastic bags with no sample					
		Plastic bag 1		Plastic bag 2		Plastic bag 3		Plastic bag 1		Plastic bag 2		Plastic bag 3		Plastic bag 1		Plastic bag 2		Plastic bag 3	
Day	Hour	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2
0	0	3.94	13.00	3.20	13.90	2.44	13.70	3.74	13.20	3.21	13.30	4.79	12.00	2.11	15.40	2.99	14.92	2.10	15.42
0	4	3.87	12.60	3.12	13.50	2.27	13.70	3.66	12.90	3.06	13.00	4.59	12.00	2.30	14.86	4.15	14.10	2.27	15.00
1	16.5	3.76	11.20	2.95	12.08	1.74	13.24	3.54	11.50	2.69	11.66	3.95	11.68	3.17	12.20	4.73	10.80	2.96	12.90
1	24.5	3.77	10.60	2.90	11.40	1.56	13.00	3.52	11.00	2.56	11.10	3.67	11.50	3.59	11.10	5.18	9.50	3.33	11.90
2	39.5	3.82	9.30	2.84	9.90	1.34	12.26	3.51	9.70	2.35	9.80	3.00	11.08	4.57	8.80	6.05	6.80	4.19	9.80
2	47.5	3.82	8.80	2.79	9.30	1.51	11.60	3.50	9.16	2.27	9.20	2.63	10.80	5.09	7.80	6.74	5.70	4.70	8.74
3	63	3.87	8.10	2.77	8.60	4.56	9.60	3.50	8.50	2.22	8.50	2.15	10.60	5.85	6.50	7.68	4.40	5.52	7.30
4	90	3.87	6.90	2.56	7.32	8.03	7.40	3.43	7.24	1.98	7.30	1.30	10.10	7.60	4.00	9.69	2.30	7.69	4.30
5	110	3.83	6.00	2.40	6.40	6.69	7.10	3.32	6.30	1.62	6.50	0.62	9.60	9.24	2.40	11.55	1.00	9.79	2.20
6	131	3.76	5.70	2.19	6.20	7.25	6.90	3.20	6.00	1.35	6.20	0.83	9.50	10.45	1.60	12.85	0.60	11.41	1.30
7	155	3.69	5.30	1.89	5.90	7.32	6.80	3.08	5.50	0.95	6.00	1.28	8.80	11.62	1.00	14.10	0.30	16.53	0.20
8	179.5	3.59	5.10	1.57	5.80	11.43	5.30	3.02	5.40	0.94	5.70	3.75	8.20	12.62	0.60	15.24	0.20	19.82	0.10
9	204.5	3.62	5.00	1.16	5.80	12.80	6.00	2.90	5.14	1.21	5.50	4.08	8.20	13.55	0.40	16.23	0.10	21.02	0.10
10	229.5	3.63	4.90	0.61	5.90	13.20	5.60	2.75	5.10	1.84	5.50	8.58	7.10	14.50	0.20	17.06	0.10	20.99	0.10
11	252.5	3.67	4.90	0.34	6.00	14.01	5.64	2.63	5.10	2.48	5.50	7.49	7.80	15.26	0.18	18.82	0.10	21.02	0.10
12	278	3.70	4.90	0.23	6.00	15.16	5.38	2.54	5.00	8.46	5.10	7.18	8.00	16.00	0.10	20.50	0.10	21.02	0.10
13	302	4.53	4.80	0.34	6.10	16.05	4.90	2.49	5.00	8.26	5.40	8.70	7.70	16.87	0.10	20.98	0.10	21.02	0.10
14	350	5.75	4.80	0.18	6.30	12.17	7.56	3.71	5.00	11.32	5.26	7.66	8.40	20.94	0.10	21.07	0.10	21.06	0.10
15	470	4.90	5.20	0.20	6.60	10.23	9.78	3.01	5.40	9.59	6.00	5.30	9.30	21.18	0.20	21.18	0.20	21.14	0.10

Table 3-2. Continued

Time		Gas Chromatography																	
		Treatment 1						Treatment 2						Treatment 3					
		Plastic bags with zucchini slices and dessicant						Plastic bags with zucchini slices						Plastic bags with no sample					
		Plastic bag 1		Plastic bag 2		Plastic bag 3		Plastic bag 1		Plastic bag 2		Plastic bag 3		Plastic bag 1		Plastic bag 2		Plastic bag 3	
Day	Hour	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2
0	0	6.26	7.21	6.34	8.04	6.75	7.42	8.17	5.75	5.65	7.76	7.44	6.66	4.96	7.53	7.11	7.62	6.06	7.82
0	4	6.69	6.69	4.95	10.12	3.55	12.15	6.78	8.92	4.93	9.47	5.98	8.74	4.91	10.04	5.13	10.15	4.95	10.65
1	16.5	8.13	6.86	5.49	8.96	4.37	11.89	8.08	6.60	5.18	8.35	6.21	9.69	7.85	8.11	7.30	7.17	6.57	9.16
1	24.5	5.72	8.94	3.55	10.35	2.10	14.11	5.39	9.98	3.65	9.69	9.66	4.70	6.13	8.48	6.73	6.73	5.70	8.95
2	39.5	6.68	5.25	4.32	7.16	2.67	8.99	5.91	6.22	4.14	6.53	3.95	7.84	7.43	5.29	8.72	4.00	5.67	6.93
2	47.5	10.95	4.81	6.49	6.50	4.99	9.98	9.14	5.97	6.85	6.45	9.11	5.55	10.03	4.95	9.99	3.74	7.97	7.30
3	63	6.57	5.45	4.68	6.43	5.44	10.31	6.39	5.56	4.72	6.94	4.03	9.63	9.06	3.80	10.73	2.29	7.13	6.11
4	90	5.63	3.27	3.71	5.74	5.07	8.39	6.21	3.51	4.74	3.64	2.49	7.10	8.43	2.00	10.22	0.47	8.56	2.43
5	110	8.78	3.35	5.39	4.84	9.30	5.21	7.87	4.41	5.81	5.58	3.30	7.94	1.36	13.67	15.07	0.00	13.16	1.51
6	131	5.69	2.97	3.86	4.00	8.17	4.33	5.60	3.64	3.07	3.25	2.72	5.53	11.57	0.66	12.58	0.00	10.53	0.02
7	155	4.43	2.68	3.86	2.87	8.28	5.00	5.33	3.32	2.87	2.92	3.68	5.76	12.53	0.00	14.33	0.00	16.23	0.00
8	179.5	5.60	2.49	2.95	4.46	7.59	5.87	4.12	3.31	3.08	2.84	4.74	5.89	13.09	0.00	14.46	0.00	19.52	0.00
9	204.5	4.47	2.92	2.23	3.83	13.07	4.71	4.47	2.31	2.54	4.20	4.58	6.00	13.69	0.00	15.78	0.00	20.38	0.00
10	229.5	5.04	2.23	2.17	3.26	11.78	5.49	4.05	3.16	4.17	3.53	9.45	5.76	14.03	0.00	16.39	0.00	20.68	0.00
11	252.5	4.44	4.21	2.41	4.98	13.92	5.31	2.93	4.65	3.86	3.46	7.93	5.47	14.67	0.00	18.37	0.00	20.26	0.00
12	278	5.38	2.84	1.57	3.25	14.84	3.87	4.25	3.00	9.78	3.30	8.27	5.59	16.30	0.00	20.14	0.00	20.34	0.00
13	302	6.13	3.34	2.43	3.25	14.63	4.70	3.90	2.82	9.41	3.32	9.59	5.67	16.75	0.00	20.21	0.00	20.11	0.00
14	350	7.90	2.20	2.22	4.09	12.29	5.78	6.01	2.45	10.94	3.92	8.24	5.54	20.08	0.00	20.99	0.00	20.31	0.00
15	470	6.36	3.75	3.00	3.58	8.17	9.90	5.24	3.18	9.90	2.86	5.92	7.15	20.25	0.00	19.90	0.00	20.13	0.00

Electronic Nose Measurements

An electronic nose (e-nose 4000 model, EEV Inc., Amsford, NJ) equipped with twelve conducting polymer sensors (sensor types: 301, 298, 297, 283, 278, 264, 263, 262, 261, 260, 259, 258) was used to quantify the sensor responses to differences in odor of slices of zucchini squashes CA stored in different gas combinations. The electronic nose measurements were done every other day up to 12 days. Five replicates (25g / jar) were analyzed by the electronic nose for each treatment. Each replicate was kept at room temperature for 30 min prior to analysis in order to let the slices equilibrate to room temperature (22˚C to 23˚C). One day before the experiment, the electronic nose was calibrated with 75% v/v propylene glycol solution (100% solution from Fisher Scientific, No. P-355-20, Fair Lawn, NJ), following the manufacturer's recommendation. Everyday before the experiments, electronic nose was turned on and compressed air (CGA Grade D, Strade Welding Supply Inc., Jacksonville, FL) was passed through the sensors for at least 30 min. The vessel was purged with compressed air for 2 min to eliminate any foreign odor present in the vessel from the environment for each replicate, and then the sensor head was purged for 4 min with compressed air. During these 4 min, the sample volatiles were equilibrated in the headspace of the vessel. Sensor response data was acquired for 4 min. Total analysis time for each zucchini sample took 10 min. Readings at 4min exposure of the sensors to the zucchini samples were used for data analysis. At the end of the day, electronic nose sensors were cleaned with compressed air for at least 30 min. Electronic nose raw data can be obtained from Dr.Murat Balaban, Food Science and Human Nutrition Department at the University of Florida (filenames:\\thesis\e-nose data.txt").

Color Analysis

The color of the zucchini slices stored under CA were measured using a color machine vision system described by Luzuriaga et al. (1997) and Luzuriaga (1999). It consisted of a light box, a color video camera, a frame grabber and a computer. The light box was built of 100% clear acrylic safety glazing sheets as described by Luzuriaga et al. (1997). The box had top and bottom lighting with 2 flourescent lights each. The chamber side of the boxes had a white translucent Polycast acrylic (No. 2447, Polycast Technology Corp., Stanford, CT) 6.35 mm thick with51% light transmission. Eight slices from each treatment for CA experiment were placed in the light box with the top lighting, and the door of light box was closed. An image of zucchini slices was taken with a CCD (charge couple device) video camera (Sony SSC-S20, Sony, Japan) with 24 bit color, 525 lines, and horizontal resolution of > 460 lines, located at the top lighting box between the 2 fluorescent lights (illuminant D50, simulating noonday summer sun, General Electric, Cleveland, OH, 1999). A lens (focal length 6-12mm, model 12VM612, Tamron Industries Inc., New York, NY) was positioned 49.5 cm above the surface of the bottom lighting box. The S-video output of the camera was connected to a color frame grabber (Matrox Meteor, Matrox, Canada) placed inside a Pentium 133 Mhz PC computer. The frame grabber was used for acquiring 24-bit color images with 640 x 480 pixels. During image acquisition a standardized color tile was placed next to the zucchini slices in the light box. Beige color tile ($L^*=84.58$, $a^* = 1.75$, $b^*= 45.42$) was used. During continuous grabbing, the color analysis program, which was used to extract color information from a color image, allowed us to change brightness, contrast, hue or saturation of the images. Settings were done to make the color of captured images close to that of the real color of the samples. Then these settings were saved. The settings in the CA experiment were: hue=1, saturation= 198, contrast=170, and brightness= 146 (settings ranged from 0 to 255). Then, images were captured and saved as TIFF (Tag image File Format, version 6.0) every other day up to 12 days for color analysis. As soon as pictures were taken, slices were placed back in jars and put in the refrigerator. They remained at room temperature no more than 10 minutes. The background of images were cleaned and saved as bmp file in Corel Photo-PAINT 7. Then color data was extracted from each slice. The program looked at every pixel in the slice and read the RGB values. The RGB values were converted to 512 color blocks. Average color was also measured in the L* a* b* color system. Color calibration was done. Reference tile averages were calculated and one was selected as "basis". The differences between the L* a* b* values of this and all the other tiles were used for calibration. During calibration the binary threshold was changed to 254 for R, G, B. Next, in "analysis option", "show binary image at the end of the analysis", "multiple data in same file" and "display color data as % of total area" were selected. Finally, "apply color calibration to image" and "known L* a* b* values" were chosen in color calibration option and saved. Then, cleaned images were opened ,and the correction factors were input to average L* a* b* values. Corrected images were saved as bmp files. Calculation of correction factor for L was shown as an example in equation 2.

$$L^*_{\text{slices in picture}} + (L^*_{\text{basis tile}} - L^*_{\text{tile in picture}}) = L^* \text{ calibration value} \qquad (2)$$

Colors of the corrected images were analyzed. Data were displayed in a spreadsheet by the program. These were saved in Microsoft Excel format (xls). The program generated a matrix of n x m color data, where n= number of color blocks, and m= number of objects in the image. Color data were reported in percent of the total area of the slice covered by a given color block. The average and standard deviations of the L* a* b* values for each slice was also calculated. Graphical representation of color data were displayed in the form of histograms. Color blocks whose values were above 5% of the total area of the slice were retained. This simplified the color data and presented the most important colors in the zucchini slices. Histograms showed the color block numbers in X axis and the % area of the slice in the Y axis. These graphs were plotted and saved in the Windows Metafile format. A descriptive list of 512 color blocks are displayed in Appendix C. It contains the RGB values at the center of each color block, the corresponding L*a*b* value, the NBS color name, and a painted rectangle with the color of the center of the block. Raw data can be obtained from Dr. Murat Balaban, Food Science and Human Nutrition Department at the University of Florida, filename: \\thesis\text files\ chap 3\ zucchini color data.txt.

Sensory Analysis

Sensory panelists were selected from graduate students, ages 25-45, in the Food Science and Human Nutrition Department at the University of Florida. Descriptive analysis was performed every other day for controlled atmosphereexperiments. Eight panelists for controlled atmosphereand 15 panelists for first and second experiment were trained in five sessions before experiments : they were presented with zucchini samples representing different storage stages (e.g. good, medium, bad, and fresh) stored at 10°C 95% RH. The panel leader compiled a descriptor list from published literature on cucumber and zucchini to aid panelists in verbalizing odor, color, surface, taste and texture characteristics perceived in the samples. The panel discussed the samples and created a list of attributes and keywords to describe them. The panel agreed on 2 odor attributes (off-odor and fresh zucchini aroma), 2 color attributes (browning and discoloration in flesh color; yellowness and greenness in peel color), 3 taste attributes (sweetness, sourness and bitterness), and 2 texture attributes (hardness and crispness). The panel leader did not influence panelists into including more attributes to describe zucchini odor, color, taste and texture. Descriptor intensity was rated using a 15 cm, unstructured line scale with a low intensity on the left side and high intensity on the right side as anchor terms. Panelists practiced rating the samples 4 times using paper ballots (Appendix B) during two different days in the morning from 9:30 am to 11:00 am. Results from training session were summarized, quantified and analyzed by SAS v 8e (SAS Institute, Cary, NC, USA) using ANOVA with the general linear model. Duncan's Multiple Range test for each attribute were used for mean separation ($\alpha= 0.05$).

For CA experiment, at each sampling day, a random sample was collected from each treatment. Approximately 20 min before sensory analysis, three slices from each treatment were placed in 118 ml Solo Brand cups (Gainesville Paper, Gainesville, FL), sealed with PS 4 lids (Gainesville Paper Inc., Gainesville, FL) and labeled with a three-digit random number. Slices were at room temperature (about 23°C) at the time of sensory analysis, and they were presented to panelists in normal light laboratory conditions. Coded hidden fresh zucchini slices were included in the test as reference. The numbers given to samples from each treatment for each time interval were different and randomized. Duplicate samples with different code numbers were also presented to panelists in different trays, randomly, after 15 min break from first tray presentation. Panelists were instructed to open the lid from each sample cup in a given order to rate the odor, color and texture descriptors. In any given session, panelists were asked to rate the attributes of 4 coded samples :2% O_2 +7%CO_2, 2% O_2 +15%CO_2, air, and a reference (daily fresh sample) in each replication using paper ballot (Appendix B). Samples used for sensory analysis in controlled atmosphereexperiment were not the same samples measured by the electronic nose, color, texture and microbiology, but were selected randomly from the same plastic container (200g) of zucchini slices from each treatment.

Microbial Analysis

Total aerobic plate counts were performed for each treatment at each sampling time using aerobic count plate petrifilm (3M Company, St. Paul, MN) for each sample at every storage time interval.

Dilutions were made using pre-filled sterile Bacto®Peptone's buffer (0.5%) dilution bottles prepared by using Bacto®peptone powder, enzymatic digest of protein, (Bacto®Peptone, Cat no:0118-17-0, Lot 103478JA, Difco Laboratories, Detroit, MI) and distilled water. 5g samples from each treatment were chopped into small pieces and put into 50 ml disposable sterile centrifuge polypropylene tubes with plug seal caps (Fisherbrand ®, Cat no:05-539-7 , Lot no: 00800001, Fisher Scientific Inc, Pittsburgh, PA), and bottles were centrifuged using vortex (Touch mixer Model 232, Fisher Scientific, Serial No: 903N0117, cat no: 12-811-10, Pittsburgh, PA) for 1 min. Four replications from each treatment, two from one container and other two from the replication container, representing the same treatment, were prepared to assure homogeneity. 1 ml sample was transferred from 45 ml sterile centrifugal plastic bottles to 9ml prefilled sterile Bacto®Peptone's buffer (0.5%) dilution glass tubes with screw caps. Serial dilutions were performed. From predetermined dilutions, 1 ml sample was taken and plated in the petri films for aerobic microbial count. Petri films were incubated at 32°C for 48 hr. Duplicate platings were performed. Colonies were reported as $\log_{10}$ colony forming units (cfu) per gram of sample ($\log_{10}$ cfu/ g of zucchini). A 1 ml was taken from control samples, directly plated on petri films and incubated at 32°C for 48 hrs. Microbial counts were performed on the control sample to see whether there was any contamination occurred during filling dilution bottles. All sets used for data analysis were sterile and free of contamination.

Texture Analysis

The Instron Universal Testing Machine (Model 4411, Instron Corp., Canton, MA) was used to determine shear force and compression for controlled atmosphereCA experiment. Slices (5 mm in thickness, 2-3 cm in diameter) were placed on their flat surface for compression and shear tests. Compression was done by the probe #15 which covered whole surface of the slice. The maximum shear force was performed using a custom designed shear blade (0.7mm in thickness, 67.7 mm in length, 40.5 mm in width, 1.8 mm sharp edge, Machine Shop, University of Florida, Gainesville, FL). It was used as an indicator of hardness and crispness of the tested zucchini slices.

To decide on load cell speed before CA experiment, a controlled atmosphereexperiment was performed using four different load cell speeds (25, 50, 75 and 100 mm/min) to compress (puncture) and cut slices (shear). For this test, zucchini squashes were purchased from Publix grocery store in Gainesville, FL, on March 22nd, 2000. For each speed, five zucchini slices were tested. Table 3-3 shows the puncture and shear force results for these load cell speeds.

Table 3-3. The results for the puncture and shear test for different load cell speeds.

Load cell speeds (mm/min)	Puncture force (kg)	Standard Deviation	Shear force (kg)	Standard Deviation
25	18.436	0.294	0.836	0.019
50	23.164	0.637	0.839	0.119
75	23.528	0.276	0.833	0.049
100	22.434	0.427	1.051	0.160

A one way ANOVA was applied to these data using SAS v 6.12 (SAS Institute, Cary, N.C., USA). No significant difference between different load cell speeds was found. Thus, 75mm/min was selected for the CA experiment for both compression and shear cutting test.

During CA experiment, the zucchini slices were placed on their flat surface (2-3 cm in diameter, 5-6mm in thickness) in the Instron for shear force test. The whole slice was cut in diameter with a same blade and compressed using same probe explained above. The maximum shear forces (kg) were measured with 50Kg load cell, and 75 mm/min load cell speed. Five slices from each treatment were used every other day. Zucchini slices were randomly selected from each plastic container representing each treatment. Same samples used for electronic nose readings and color analysis were used for texture analysis. All texture measurements were done at room temperature (22-23°C).

Modified Atmosphere Packaging Study

General Preparation

The same preparations as above were performed.

Plastic Bags

Two different plastic bag types were used. These bags were provided by Redi-Cut Company (Chicago, IL), manufactured by PPC industries, Inc. (Pleasant Prairie, WI):

> 1) heat-sealed plastic bags of multilayer linear low density polyethylene (LLDPE) (60%) and low density polyethylene (LDPE) (40%) films (no: 731002), 50μm, manufactured by PPC industries, Inc. (Pleasant prairie, WI), and gas-exchange surface area of 336 inch^2 (12x14inch). Named P1 in this study.
>
> 2) heat-sealed plastic bags of multilayer linear low density polyethylene (LLDPE) (70%) and low density polyethylene (LDPE) (30%) films (no: 731004), 70 μm, manufactured by PPC industries, Inc. (Pleasant prairie, WI), and gas-exchange surface area of 336 inch^2 (12x14inch). Named P2 in this study.

The plastic bags were sent to Mocon Company to measure their gas permeation rates. Results were shown in Table 3-4.

Table 3-4. Gas permeability rates of the plastic bags used for MAP study.

Experiments	Plastic bags	Transmission rates (mmoles x m)/(m^2 day atm)							
		CO_2				O_2			
		Rep1	Rep 2	Avg	Std	Rep 1	Rep 2	Avg	Std
I	P1	0.0353	0.0326	0.0340	0.0019	0.0057	0.0054	0.0056	0.0002
	P2	0.0261	0.0265	0.0263	0.0003	0.0041	0.0043	0.0042	0.0001
II	P1	0.0277	0.0229	0.0253	0.0034	0.0042	0.0039	0.0041	0.0002
	P2	0.0216	0.0222	0.0219	0.0004	0.0038	0.0039	0.0039	0.0001

Utensils

Utensils were cleaned and sterilized as described above. Eighty eight plastic shelves (28.5 cm (l) x 23.5 cm (w) x 1cm (h)) were made from Rubbermaid® twin sink protector (cat no: 1295, Newell Rubbermaid Company, Wooster, OH). The hole located at the center was covered with plastic mesh (1" hardware cloth, Home Depot, Gainesville, FL). Four stoppers were glued with silicon to each corner of plastic shelves to provide extra height (2.5 cm) for gas diffusion into slices from below. These shelves were also sterilized by swabbing with ethyl alcohol (95%).

Cleaning Water

The same procedure mentioned above was used.

Minimal Processing

For experiment I, Zucchini squash (*Cucurbita pepo L. cv.* Senator) were obtained from the F &T farm in Homestead, Florida on April 20th, 2001. The study was replicated with zucchini squash (*Cucurbita pepo L. cv.* Elite) obtained from Publix grocery store in Jacksonville Florida during summer, for experiment II. Zucchini squash were picked from a farm located in Saginaw, Michigan on August 11th, 2001 and transported (4°C, 95%) to Jacksonville, FL same day. Fresh zucchini squash came in 10 boxes of half bushels in both experiment I and experiment II. Zucchini squash from experiment I and II were stored at 5°C cold storage with 95% RH for a night. Next day, minimal processing was performed at 5°C cold storage with 95% RH. Same procedure was followed as CA experiment. Slices were placed on the plastic shelves and put into two different plastic bags (~280g/per bag). The bags were first vacuumed, then flushed with gas combinations and immediately sealed by Vacuum Impulse Sealer Tabletop (18/24 series - PVTG / PVTG / S with gas flush option, Packaging Aids Corporation (PAC), San Rafael, CA) in cold storage (5°C, RH=95%). PAC Vacuum Impulse Heat Sealer (table-top) was tried in this experiment. It consists of vacuum impulse heat sealer, pneumatic operated sealing jaws, gas -flush system and safety features. For pneumatic operation, 80-120 psi line pressure filtered air is required. Standard air tank and 2%O_2+15%CO_2 gas tanks (Spec

Connection International Inc. Analytical Laboratories, Lutz, FL) were connected to gas inlet at the back of the machine using 40 psi maximum pressure.

Samples were subjected to two different MA conditions 2%O_2+15%CO_2 balance N_2, and air (21% O_2 as initial). 2%O_2+7%CO_2 was not used because more shelf life extension with the best quality was obtained from 2%O_2+15%CO_2 during CA experiment. Two replications from each treatment were prepared for each sampling day. As soon as plastic bags were sealed and labeled, they were placed on the trays (previously cleaned, swabbed with ethyl alcohol (95%)), labeled, and transferred to a cold storage (5°C, RH=95%) located at Fifield Hall, Horticulture Department, Gainesville, FL. Samples for experiment I and II were stored up to 24 days and 17 days, respectively. Two plastic bags from each treatment were transported in Igloo coolers from Fifield Hall, Horticulture Department, Gainesville, FL, to Food Science and Human Nutrition Department, Gainesville, FL, every sampling day. They were evaluated for changes in objective quality parameters such as odor, color, texture etc. using electronic nose, machine vision and Instron as well as organoleptic quality parameters using 15 trained panelists. Aerobic microbial count was also performed using 3M petri film. Oxygen and carbon dioxide levels inside the bags were measured using the headspace analyzer.

Gas Concentration Measurement

Oxygen and carbon dioxide concentrations inside the bags were measured every day throughout storage for experiment I and II. Gas levels were analyzed using a PBI Checkmate 9900 O_2/CO_2 headspace analyzer (Topac Inc., Hingham, MA) after it was proven that it was better than GC. A needle was connected to Checkmate by a tube. Using the septa on plastic bags eliminated leaks and kept the package airtight.

Electronic Nose Measurements

The same procedure and equipment was used as CA experiment. The electronic nose measurements were done at days 0, 3, 6, 8, 10, 13, 15, 17, 22, and 24 for experiment I and at days 0, 3, 6, 8, 10, 13, 15, 17 for experiment II. Six replicates were analyzed by the electronic nose for each treatment. Electronic nose raw data from experiment I and II can be obtained from Dr. Balaban, Food Science and Human Nutrition Department at the University of Florida (filenames:\\thesis\e-nose data.txt").

Color Analysis

The experiment I and II results were analyzed with the same system described in CA experiment. Pictures of twelve slices from each treatment for both experiment I and II were taken at 0, 3, 6, 8, 10, 13, 15, 17, 22, 24 days for experiment I, and at 0, 3, 6, 8, 10, 13, 15, 17 days of storage for experiment II. The same beige color tile was placed next to the zucchini slices in the light box. The settings for the video camera in the all experiments were the same as controlled atmosphere experiment settings. The method used for calibration and color analysis were the same as above. After the images were taken, slices were placed back in jars and put in refrigerator (4-5 °C). They remained at room temperature no more than 10 minutes. Color was reported in the RGB and L*a*b* color systems. Raw data can be obtained from Dr. Murat Balaban, Food Science and Human Nutrition Department at the University of Florida, filename: \\thesis\text files\ chap 3\ zucchini color data.txt.

Sensory Analysis

The same procedure mentioned in CA experiment were run for MA experiment. 15 trained panelists from graduate students, years of age 25-45, in the Food Science and

Human Nutrition Department at the University of Florida, were also used in this experiment. Quantitative descriptive analysis was performed at days 0, 3, 6, 8, 10, 13, 15, 17, 22 and 24 for experiment I, and at days 0, 3, 6, 8, 10, 13, 15, 17 for experiment II during storage. 15 panelists were trained. It was necessary to do another training session for panelists because not only some panelists left, but also some joined after the CA experiment. During training sessions, panelists were presented with good, medium, bad and fresh samples stored in MAP at 5˚C and 95% RH., using two different gas compositions and two different plastic bags. The ballot was slightly different than the one used in CA experiment. The panel decided on 2 odor attributes (off-odor and fresh zucchini aroma), 2 color attributes (white-yellow and degree of transparency), 2 surface attributes (surface breakdown and dry-wet), 4 taste attributes (sweetness, bitterness, off-flavor and fresh zucchini flavor), and 2 texture attributes (hardness-softness and crispness). Descriptor intensity was rated using a 15 cm, unstructured line scale with a low-high intensity from right to left side as anchor terms. Panelists practiced rating the samples 4 times during four different days. For experiment I, at each sampling day from 1-5 pm in the afternoon, a random sample was collected from each treatment. Approximately 20 min before sensory analysis, three slices from each treatment were placed in 118 ml Solo brand cups (Gainesville Paper, Gainesville, FL), sealed with PS 4 lids (Gainesville Paper, Gainesville, FL) and labeled with a three-digit random number. Slices were at room temperature (about 22-23˚C) during sensory analysis. For experiment I, samples were presented to panelists in day light laboratory conditions, using paper ballots (Appendix B). Coded hidden fresh zucchini slices as reference were included in the test. The numbers given to samples from each treatment for each interval time were different, and they were randomized. Replication with different codes (five coded samples) were arranged on different foam trays. These second trays were presented randomly to all panelists after 15 min break from the first evaluation. Panelists evaluated each sample in order. For experiment II, a computerized taste panel procedure was followed using Compusense 5 v 4 software (Compusense Inc., Anaheim, CA) to create Quantitative Descriptive test. Sample preparation was the same as experiment I. Panelists used computerized sensory ballots. Evaluations were conducted in individual booths with dim lighting. Five coded samples and their replication with different code numbers were presented in random order. Samples used for sensory analysis in both experiment I and II were not the same samples as the ones measured by the electronic nose, color, texture and microbiology.

Microbial Analysis

Same procedure used in CA experiment was applied to count total aerobic bacteria using 3M petri film for experiments I and II. The only difference was sampling times which were at days 0, 3, 6, 8, 10, 13, 15, 17, 22, and 24 for experiment I and at days 0, 3, 6, 8, 10, 13, 15,and 17 for experiment II.

Texture Analysis

Shear force was measured using the Instron for MA experiments because results from puncture force test during CA experiments was not good enough to show textural changes over time. Zucchini slices were randomly selected from each plastic bag representing different treatments. Same samples used for electronic nose readings and color analysis were used for texture analysis.

The same procedure was used for shear force testing during MA for both experiments I and II. The zucchini slices were placed on their flat surface (2-3 cm in diameter, 5-6mm thick). The blade moved downwards in the Instron. Two different cutting styles were performed using two different custom made blades. First, the whole slice was cut diametrically with a custom designed shear blade (0.7mm in thickness, 67.7 mm in length, 40.5 mm in width, 1.8 mm sharpen edge, Machine Shop, University of Florida, Gainesville, FL). Second, the slice was cut around the seed area with a small custom designed shear blade (0.9mm in thickness, 67.5 mm in length, 19 mm in width, 1.9 mm sharpen edge, Machine Shop, University of Florida, Gainesville, FL). Five slices from each treatment for both applications were measured to calculate the maximum shear force (kg) for every interval of time during experiment I and II. The maximum shear forces (kg) were used as an indicator of hardness and crispness. The shear force parameters were: F= 50Kg load cell, and 75 mm/min load cell speed. All measurements were done at room temperature (22-23°C).

Statistical Analysis

Principal component analysis (PCA): PCA was done to reduce the set of variables to a smaller set that contains fewer variables. The fewer variables are functions of the original variables or of those that contain a significant proportion of total information available in the data set (Khattree and Naik, 2000). In this study, for example color data set was reduced using PCA, and reduced color data set was correlated with sensory data to have a better correlation coefficient. The same procedure was also applied to e-nose data.

PCA was used to examine the degree of covariability among data. The output of PCA analysis lists the Eigenvalues with their proportions of explained variance. To select the number of principal components to describe the given data, the components' importance should be considered until the fraction of cumulative variance exceeds some pre-specified level, usually 90-95% in the natural sciences (Khattree and Naik, 2000).

Canonical discrimination analysis (CDA): Canonical discrimination analysis is a dimensionality reduction technique similar to PCA and canonical correlation analysis. It is, however, specialized to the context of discriminant analysis and is used to provide a representation of various populations in a subspace of smaller dimensions. Based on a large number of possibly correlated characteristics on which measurements are taken, the analysis attempts to obtain a set of a linear combinations of a few variables that can separate the various populations. These new variables obtained as certain linear combinations of original measurements are termed canonical variables. In general, the extraction of various canonical variables does not require any distributional assumption such as multivariate normality. This assumption is needed, however, when certain statistical tests, such as the determination of the number of important canonical variables, are to be performed. However, with or without any distributional assumption, the canonical discrimination analysis is applicable only when all populations have a common variance-covariance matrix. Since the basic interest is in the reduction of dimensionality of the data, one question that can be asked is what is the minimum number of canonical variables that can adequately describe the data and adequately discriminate among the groups. This question can be addressed by asking how many of these canonical correlations are significantly different from zero. We can determine the number of important canonical variables and hence the corresponding dimensionality of the data (Khattree and Naik, 2000) .

Canonical correlation: Canonical correlation analysis is a technique to identify and measure the association between two sets of random variables using specific matrix function of the variance-covariance matrix of these variables. It was performed using SAS (v8 e). It is easier to understand and interpret these relationships if the variables in each of two sets can be transformed to fewer and uncorrelated variables so that there is a one-to-one correspondence between the variables in two transformed sets. In canonical correlation, we look for v and w vectors. In multivariate regression contex, v represents the vector of predictor variables and w that of the criterion or response variables (Khattree and Naik, 2000).

Data Analysis

Electronic nose sensor readings and color data were analyzed in Statistica for Windows ('98 edition, Statsoft Inc, Tulsa OK) and SAS using discriminant function analysis (DFA). Storage time and different treatments were used as grouping variables and 12 electronic nose sensors and color data were used as independent variables. DFA was used to construct predictive functions to classify electronic nose data based on the grouping variables. The 12 sensor outputs were reduced to 2 discriminant functions. These functions were used to map electronic nose data in 2 dimensional plots and observe separation between groups. Correct classification rates (CCR) were calculated for both electronic nose and color data. Colors blocks with color values above 2% were selected for analysis, and reduced to 2 discriminant functions to calculate the correct classification rates. Cross validation analysis was also performed. In cross validation analysis, all sample #1's in each treatment were removed from the data set and DFA performed on the remaining 11 data to find classification functions and CCR. Sample #1 data were then classified using these functions. This was applied to samples #2 to 12, one set at a time for color and electronic nose data.

Color data were analyzed by searching for trends in specific colors in the discrete spectrum of colors. Average color profiles were plotted to observe the differences in the color patterns among different treatments. Also average L*a*b* values were obtained using color machine vision system.

Texture and microbial data were analyzed by ANOVA using a randomized block design with repeated measures analysis in time (SAS Institute, Cary, N.C.). Least square means were obtained and separated using the least significant difference test procedures when significant ($p < 0.05$) F values were obtained.

Sensory and gas measurements data were analyzed using ANOVA and Duncan's Multiple Range test was used for mean separations with SAS. The effects of panelists were also investigated. Objective readings and organoleptic evaluations were correlated using Canonical Discrimination method (SAS v8e, 2001). Color data and e-nose data were also reduced using principal component analysis (PCA). Their discrimination was also observed using Canonical Discrimination Analysis (SAS v8e, 2001).

CHAPTER 4
RESULTS AND DISCUSSION

Microbial Analysis

Microbial counts for air, $7\%CO_2+2\%O_2$ and $15\%CO_2+2\%O_2$ treatments during 12 days of storage for zucchini slices stored under controlled atmosphere in the controlled atmosphere (CA) experiment are given in Table 4-1. Analysis of variance with the general linear model procedures was performed for the CA to see if there was a significant difference between treatments (gas mixtures, and time). It was expected that exposing zucchini slices to different gas combinations as treatments and time would have an effect on the microbial load. It was found that treatments, time, and their interactions were significant ($p<0.001$).

The microbial loads of each treatment for the CA experiment were plotted versus storage time (Figure 4-1). In general, total aerobic counts increased gradually during storage, but they increased more rapidly for air (control) samples. The increase of total aerobic microbial counts at $7\%CO_2+2\%O_2$ treatment showed a similar trend with that of $15\%CO_2+2\%O_2$. They both showed lower total microbial counts than the control samples throughout storage. In the CA experiment, $15\%CO_2+2\%O_2$ treatment showed lowest and slowest increasing microbial counts for up to 10 days, since elevated CO_2 and controlled atmosphere suppressed microbial growth. Total aerobic counts exceeded 10^9 cfu/g at day 12 for all treatments for the CA experiment. Since microbial counts in excess of 1×10^6

Table 4-1. Microbial loads of zucchini slices stored under different controlled atmosphere conditions.

Treatment	Storage Time (Days)	Microbial Load ($\log_{10}$ cfu/g)*	
		Controlled Atmosphere Experiment	
		Avg.	St.dev.
Air	0	3.53	0.09
	2	6.27^a	0.08
	4	7.51^a	0.09
	6	8.78^a	0.09
	8	9.50^a	0.08
	10	9.91^a	0.09
	12	9.86^a	0.09
$7\%CO_2+2\%O_2$	0	3.56	0.09
	2	5.12^b	0.08
	4	6.69^b	0.09
	6	7.41^b	0.09
	8	8.36^b	0.08
	10	9.07^b	0.09
	12	9.47^b	0.09
$15\%CO_2+2\%O_2$	0	3.57	0.09
	2	4.65^c	0.08
	4	5.94^c	0.09
	6	6.77^c	0.09
	8	7.90^c	0.08
	10	8.74^c	0.08
	12	9.05^c	0.09

*: Average of four readings

$^{a\text{-}c}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

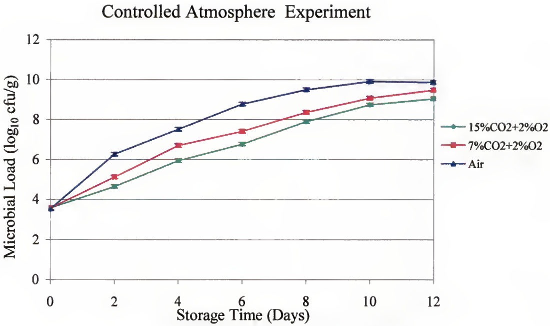


Figure 4-1. Average microbial load of zucchini slices stored under different controlled atmosphere conditions at constant temperature over time during controlled atmosphere experiment. Error bars signify ± standard deviations.

cfu/g or 1x 10^7 cfu/g are required to produce adverse defects on product quality (Barriga et al., 1991), formation of off-odors, discoloration, softness and sliminess etc. was expected. Quality changes were detected by the electronic nose, color machine vision and Instron.

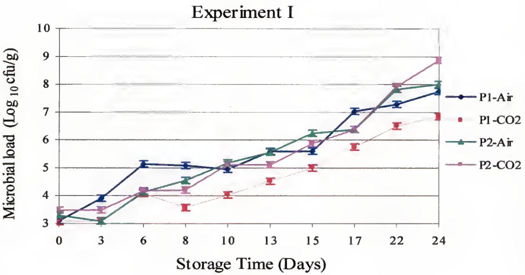
Microbial counts for air (P1-Air and P2-Air) and 15%CO_2+2%O_2 (P1-CO_2 and P2-CO_2) in first and second plastic bag treatments, respectively, during 24 days of storage of first experiment, and during 17 days of storage of second experiment for zucchini slices stored under modified atmosphere are given in Table 4-2. Analysis of variance with the general linear model procedures showed that modified atmospheres as treatments, time and their interactions were significant ($p<0.001$) for experiments I and II. The microbial loads of each treatment for experiments I and II were plotted versus storage time (Figure 4-2). Aerobic microbial populations for P1-Air, P1-CO_2, P2-Air and P2-CO_2 ranged from 10^3-10^4 cfu/g at day 0. Increases in populations for P1-CO_2, P2-Air and P2-CO_2 were similar through day 6 of storage in experiment I. However, the growth rate of aerobic microorganisms for P1-CO_2 and P2-CO_2 slowed between days 6 and 8. After day 8, steady growth was observed through day 24 for P1-CO_2 and P2-CO_2 in experiment I. Populations increased more rapidly for P1-Air, P2-Air and P2-CO_2 compared to P1-CO_2. Population growth for P1-CO_2 treatment was significantly lower than the other three treatments for each day of analysis from day 8 to 24 for experiment I. Population levels were acceptable for P1-CO_2 during the first 24 days, whereas population levels for the other treatments were acceptable only up to day 17 for experiment I.

Table 4-2. Microbial load of zucchini slices stored under two different modified atmosphere conditions using different plastic bags.

Treatment	Storage Time (Days)	Microbial Load ($\log_{10}$ cfu/g)*			
		Experiment I		Experiment II	
		Avg.	St.dev.	Avg.	St.dev.
P1-Air	0	3.10^{a}	0.11	4.08	0.08
	3	3.90^{a}	0.11	4.94^{a}	0.07
	6	5.14^{a}	0.11	6.39^{a}	0.10
	8	5.09^{a}	0.11	6.30^{a}	0.07
	10	4.95^{a}	0.11	7.16^{a}	0.08
	13	5.59^{a}	0.11	7.90^{a}	0.07
	15	5.60^{a}	0.11	8.29^{a}	0.07
	17	7.04^{a}	0.11	8.50^{a}	0.07
	22	7.28^{a}	0.11	-	-
	24	7.75^{a}	0.11	-	-
P1-CO_2	0	3.06^{a}	0.11	3.96	0.07
	3	3.11^{b}	0.11	4.84^{a}	0.07
	6	4.09^{b}	0.11	5.30^{b}	0.10
	8	3.58^{b}	0.11	6.01^{b}	0.07
	10	4.03^{b}	0.11	6.38^{b}	0.10
	13	4.53^{b}	0.11	7.10^{b}	0.07
	15	4.99^{b}	0.11	7.40^{b}	0.08
	17	5.75^{b}	0.11	8.25^{b}	0.07
	22	6.51^{b}	0.11	-	-
	24	6.84^{b}	0.11	-	-
P2-Air	0	3.30^{ab}	0.11	4.29	0.10
	3	3.09^{b}	0.11	4.94^{a}	0.07
	6	4.13^{b}	0.11	6.36^{a}	0.08
	8	4.55^{c}	0.11	6.12^{ab}	0.08
	10	5.17^{a}	0.11	6.96^{a}	0.07
	13	5.57^{a}	0.11	8.11	0.07
	15	6.25^{c}	0.11	8.26^{a}	0.08
	17	6.39^{c}	0.11	8.54^{a}	0.07
	22	7.83^{c}	0.11	-	-
	24	8.01^{c}	0.11	-	-
P2-CO_2	0	3.48^{b}	0.11	3.98	0.10
	3	3.49^{c}	0.11	4.67^{b}	0.07
	6	4.18^{b}	0.11	5.23^{b}	0.08
	8	4.21^{d}	0.11	6.18^{ab}	0.07
	10	5.11^{a}	0.11	6.26^{b}	0.08
	13	5.11^{c}	0.11	7.22^{b}	0.08
	15	5.87^{d}	0.11	6.83	0.13
	17	6.38^{c}	0.11	8.35^{ab}	0.07
	22	7.93^{c}	0.11	-	-
	24	8.87^{d}	0.11	-	-

*: Average of eight readings

$^{a\text{-}d}$: Superscripts within an experiment for each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.



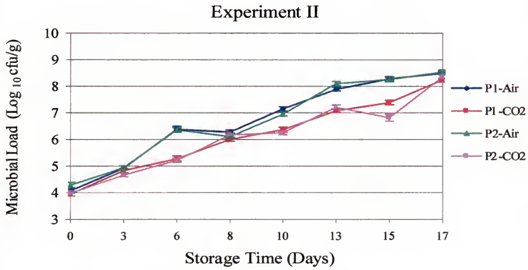


Figure 4-2. Average microbial load of zucchini slices stored under different modified atmosphere conditions and different plastic bags at constant temperature over time. Error bars signify ± standard deviations.

Regardless of gas composition, increases in populations were similar through day 17 of storage for experiment II. Populations increased more rapidly for zucchini slices stored under P1-Air and P2-Air compared to P1-CO_2 and P2-CO_2 treatments. Those for P1-CO_2 and P2-CO_2 were at least 10 times lower than those for P1-Air and P2-Air throughout day 17. This was similar to trends described by Berrang et al. (1990) who reported that controlled atmosphere storage of broccoli significantly reduced the growth of total aerobic microbial populations, and controlled atmosphere storage extended the shelf life of broccoli. Beuchat and Brackett (1990) found that after packaging shredded lettuce in $3\%O_2$+ $97\%N_2$ or in air, no significant difference could be found in populations of mesophilic bacteria. Babic and Watada (1996) reported that 0.8% O_2+10%CO_2 reduced microbial growth between 10 and 100 fold for fresh-cut spinach leaves at 5°C, except for lactic acid bacteria and yeasts. Mencarelli (1987) mentioned that whole zucchini squash stored in air showed a high percentage of mold , however the increase was slight for zucchini kept in 5% and 10% CO_2.

Texture Analysis

Texture analysis was done using shear force by blade and probe. Significant difference was detected for treatment effects, storage time and interactions between treatments and storage time when a blade was used ($p<0.05$). However, although storage time and interactions between treatments and storage time was significantly different, no significant effect was observed for treatment effect when a probe was used to determine maximum force. Results of the CA experiment at 10°C indicated that shear force using either blade or probe showed a similar decreasing trend for air and CO_2 treatments with time (Figure 4-3, Table 4-3). There was a small increase on maximum shear force for air

Table 4-3. Shear force in zucchini slices stored under different controlled atmosphere conditions over time during controlled atmosphere experiment.

Treatments	Storage Time (Days)	Maximum Load (kg)*			
		Shear Force (Big blade)		Compression (Probe #15)	
		Avg.	St. dev.	Avg.	St. dev.
Air	0	1.07	0.11	31.37	3.49
	2	1.11^a	0.11	40.80^a	3.49
	4	1.01	0.11	35.93	3.49
	6	0.78^a	0.11	16.25^a	3.49
	8	0.44	0.11	9.45^a	3.49
	10	-	-	-	-
	12	-	-	-	-
$7\%CO_2+2\%O_2$	0	1.12	0.11	31.34	3.49
	2	0.86^{ab}	0.11	33.15^{ab}	3.49
	4	1.23	0.11	32.55	3.49
	6	0.99^{ab}	0.11	27.80^b	3.49
	8	0.78^b	0.11	30.14^b	3.49
	10	0.77^a	0.11	18.32^a	3.49
	12	0.32^a	0.11	8.62^a	3.49
$15\%CO_2+2\%O_2$	0	0.98	0.11	34.23	3.49
	2	0.82^b	0.11	29.97^b	3.49
	4	1.17	0.11	31.94	3.49
	6	1.14^b	0.11	33.71^b	3.49
	8	1.00^b	0.11	21.43^b	3.49
	10	0.84^a	0.11	17.83^a	3.49
	12	0.94^b	0.11	9.40^a	3.49

*: Average of five readings

^{a,b}: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

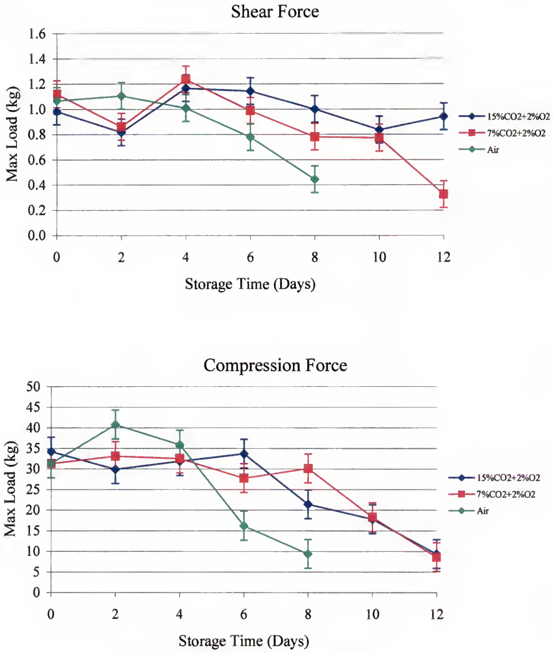


Figure 4-3. Change of shear force and compression in zucchini slices stored under different controlled atmosphere conditions over time during controlled atmosphere experiment.

treated samples at day 2. There was a gradual decrease from day 2 to day 8 for air treatment for both blade and probe. After day 8, because samples deteriorated, no readings were obtained. Maximum shear force for both $7\%CO_2+2\%O_2$ and $15\%CO_2+2\%O_2$ treatments first decreased when a blade was used at day 2. Then, shear force increased at day 4. After day 4 maximum shear force declined until day 10. At day 12, $7\%CO_2$ treatment showed further decline whereas there was a slight increase in $15\%CO_2$ treatment when a blade was used. However, when a probe was used maximum shear force at day 12 was similar for both CO_2 treatments. For each sampling time, different samples were used. As a result, the fluctuations observed at day 2 might have been due to differences in samples that were used for those days.

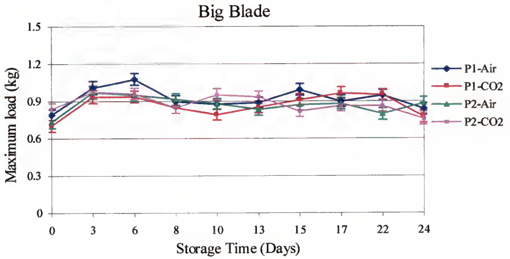
During experiments I and II, instead of a probe, two different size blades (small and big) were used because using a blade was found to be more effective in determining shear force. Results of maximum shear force using both small and big blade for experiments I and II were presented in Table 4-4 and Figure 4-4. There was a significant difference of treatment ($p<0.05$), storage time and their interactions when the big blade was used for experiment I, whereas treatment effect was not significant when small blade was used. However, significant storage time and interaction between treatment and storage time were detected for small blade. During the second experiment, there was a significant treatment, storage time and interaction effect for both small blade and big blade ($p<0.001$). During the first 10 days, differences among the treatments were not apparent and samples preserved their hardness when both small and big blade were used. On the other hand, maximum shear force was preserved better for P1-CO_2 and P2-CO_2 treatments than P1- Air and P2-Air treatments after day 10 (Figure 4-5). Results from

Table 4-4. Shear force using two different custom blades on zucchini slices stored under different modified atmosphere conditions over time for experiments I and II.

Treatments	Storage Time (Days)	Maximum Load (kg)*							
		Experiment I				Experiment II			
		Big Blade		Small Blade		Big Blade		Small Blade	
		Avg.	St.dev.	Avg.	St.dev.	Avg.	St.dev.	Avg.	St.dev.
P1-Air	0	0.79	0.04	0.58^{a}	0.03	0.98	0.05	0.58	0.03
	3	1.01	0.05	0.50	0.03	1.05	0.05	0.63	0.03
	6	1.08^{a}	0.05	0.67^{a}	0.03	1.08	0.05	0.67	0.03
	8	0.90	0.05	0.55	0.03	0.98	0.05	0.66^{a}	0.03
	10	0.88^{ab}	0.04	0.55	0.03	0.97	0.05	0.64	0.03
	13	0.89	0.04	0.61	0.03	0.74^{a}	0.05	0.49^{a}	0.03
	15	0.99^{a}	0.05	0.68^{a}	0.03	0.67^{a}	0.05	0.37	0.03
	17	0.90	0.05	0.67	0.03	0.44^{a}	0.05	0.16	0.04
	22	0.95^{a}	0.04	0.66^{a}	0.03	-	-	-	-
	24	0.84	0.05	0.52^{a}	0.03	-	-	-	-
P1-CO_2	0	0.70	0.05	0.48	0.03	0.99	0.05	0.62	0.03
	3	0.94	0.05	0.45	0.03	1.03	0.05	0.66	0.03
	6	0.94^{b}	0.05	0.70^{a}	0.03	0.97	0.05	0.70	0.03
	8	0.85	0.05	0.55	0.03	1.12	0.05	0.69^{a}	0.03
	10	0.79^{a}	0.04	0.56	0.03	1.07	0.05	0.67	0.03
	13	0.85	0.05	0.58	0.03	1.03	0.05	0.64^{b}	0.03
	15	0.91^{ab}	0.05	0.60^{ab}	0.03	0.91^{b}	0.05	0.59^{b}	0.03
	17	0.96	0.05	0.65	0.03	0.67^{b}	0.05	0.38^{b}	0.03
	22	0.95^{a}	0.04	0.68^{a}	0.03	-	-	-	-
	24	0.77	0.05	0.66^{b}	0.03	-	-	-	-
P2-Air	0	0.74	0.05	0.60^{a}	0.03	1.00	0.05	0.60	0.03
	3	0.97	0.05	0.51	0.03	1.03	0.05	0.63	0.03
	6	0.95^{ab}	0.05	0.75^{b}	0.03	0.95	0.05	0.70	0.03
	8	0.92	0.05	0.56	0.03	0.99	0.05	0.72^{a}	0.03
	10	0.88^{ab}	0.04	0.57	0.03	0.95	0.05	0.67	0.03
	13	0.83	0.05	0.59	0.03	0.96^{b}	0.05	0.61^{b}	0.03
	15	0.87^{b}	0.05	0.57^{b}	0.03	0.54^{a}	0.05	0.15^{c}	0.03
	17	0.88^{a}	0.05	0.62	0.03	0.26^{c}	0.05	0.12^{a}	0.04
	22	0.80^{b}	0.05	0.50^{b}	0.03	-	-	-	-
	24	0.88	0.05	0.66^{b}	0.03	-	-	-	-
P2-CO_2	0	0.84	0.05	0.56^{b}	0.03	1.10	0.05	0.56	0.03
	3	0.97	0.05	0.44	0.03	1.00	0.05	0.61	0.03
	6	0.96^{ab}	0.05	0.74^{b}	0.03	1.11	0.05	0.71	0.03
	8	0.85	0.05	0.50	0.03	1.02	0.05	0.60^{b}	0.03
	10	0.95^{b}	0.05	0.54	0.03	1.08	0.05	0.66	0.03
	13	0.93	0.05	0.57	0.03	0.99^{a}	0.05	0.65^{b}	0.03
	15	0.82^{b}	0.05	0.59^{b}	0.03	0.92^{b}	0.05	0.51^{b}	0.03
	17	0.86	0.05	0.65	0.03	0.79^{b}	0.05	0.43^{b}	0.03
	22	0.86^{ab}	0.05	0.65^{a}	0.03	-	-	-	-
	24	0.76	0.05	0.60^{b}	0.03	-	-	-	-

*: Average of eight readings

[a-c]: Superscripts within an experiment for each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.



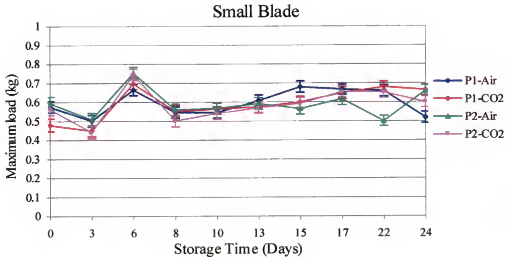


Figure 4-4. Shear force in zucchini slices stored under different modified atmosphere conditions over time using two different custom blades during experiment I

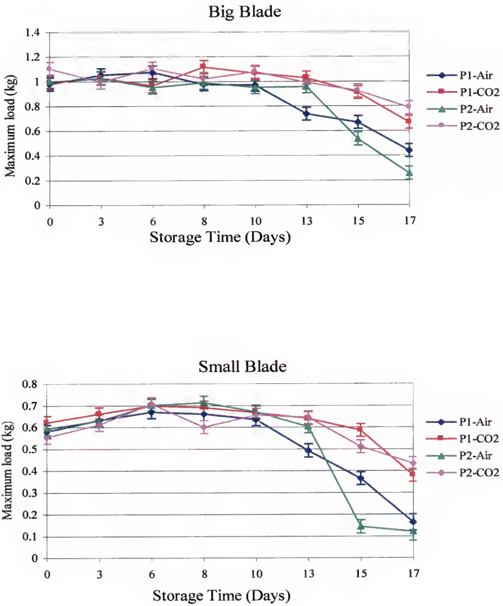


Figure 4-5. Change of shear force in zucchini slices stored under different modified atmosphere conditions over time using two different custom blades during experiment II.

CA and experiment II indicated that maximum shear force can be determined using a small or big blade. Berrang et al. (1990) mentioned that asparagus held under controlled atmosphere was significantly easier to shear throughout storage than asparagus stored under air. Although not as tender, asparagus stored under air developed a distinct soft slimy outer layer by day 14. However, in current MA study, zucchini samples stored in air were easier to shear after day 10 than zucchini samples stored under CO_2 treatments. For CA study, air samples were easier to shear after day 2 than CA samples.

Gas Measurements

Results for gas changes of all treatments during the storage for experiment I and II were presented in Tables 4-5 and 4-6. Statistically significant treatment, storage time and their interaction effects were observed for O_2 and CO_2 change over time for experiment I and II ($p<0.001$). O_2 gradually decreased for P1-Air and P2-Air treatments up to day 12 for both experiments I and II. Although O_2 was declined by day 4 in P1-CO_2 for experiment I, decrease in O_2 was slower and extended up to day 7 in P1-CO_2 for experiment II. It was found that O_2 stayed higher in P2-CO_2 treatment than P1-CO_2 treatment for both experiments I and II. O_2 levels in the bags lasted up to day 8 and day 12 for experiments I and II, respectively for P2-CO_2.

For both bags flushed with air, an increase in CO_2 levels was observed starting from day 1 up to day 6, and day 11 for experiments I and II, respectively due to respiration of zucchini slices. In both experiments, CO_2 levels were higher in P1. During experiment I, CO_2 levels for bags flushed with CO_2 treatments declined starting from day 1. The decline in CO_2 levels in P2 was greater than in P1 (Figure 4-6). During experiment II, decrease in CO_2 levels were observed up to 9 days in both P1 and P2

Table 4-5. Oxygen and carbon dioxide (%) measurements of modified atmosphere stored zucchini slices during storage for experiment I.

Treatments	Storage Time (Days)	O_2 (%)*		CO_2 (%)*		Treatments	O_2 (%)		CO_2 (%)	
		Avg	St.dev.	Avg	St.dev.		Avg	St.dev.	Avg	St.dev.
P1-Air	0	22.30^{a}	0.01	0.20^{a}	0.00	$P1\text{-}CO_2$	3.38^{b}	0.02	14.33^{b}	0.08
	1	17.95^{a}	0.28	3.43^{a}	0.22		2.23^{b}	0.93	12.14^{b}	0.50
	2	14.55^{a}	0.45	5.70^{a}	0.27		0.68^{b}	0.53	11.05^{b}	0.24
	3	12.29^{a}	0.48	6.99^{a}	0.22		0.20^{b}	0.23	10.19^{b}	0.20
	4	10.32^{a}	0.56	7.91^{a}	0.20		0.09^{b}	0.12	9.54^{b}	0.23
	5	8.49^{a}	0.64	8.33^{a}	0.63		0.09^{b}	0.14	8.85^{b}	0.37
	6	7.10^{a}	0.64	8.39^{a}	0.79		0.07^{b}	0.13	8.26^{b}	0.34
	7	5.82^{a}	0.69	8.55^{a}	0.88		0.03^{b}	0.03	7.97^{b}	0.27
	8	4.25^{a}	0.69	8.54^{a}	1.02		0.08^{c}	0.15	7.83^{b}	0.32
	9	2.77^{a}	0.81	9.10^{a}	1.20		0.05^{c}	0.06	7.93^{b}	0.39
	10	1.30^{a}	0.78	9.00^{a}	1.13		0.04^{b}	0.04	7.72^{b}	0.38
	11	0.45^{ac}	0.54	9.15^{a}	1.08		0.03^{c}	0.03	7.97^{b}	0.51
	12	0.04^{a}	0.03	8.85^{a}	1.09		0.03^{a}	0.04	7.77^{b}	0.32
	13	0.09^{a}	0.20	8.92^{a}	0.31		0.08^{a}	0.18	7.71^{b}	0.23
	14	0.10	0.21	8.80^{a}	0.32		0.05	0.13	7.81^{b}	0.18
	15	0.02^{a}	0.00	8.37^{a}	0.11		0.02^{a}	0.03	7.87^{b}	0.13
	16	0.01^{a}	0.01	8.31^{a}	0.13		0.01^{a}	0.00	7.89^{b}	0.15
	17	0.01^{a}	0.00	8.26^{a}	0.16		0.01^{a}	0.00	7.99^{a}	0.30
	18	0.03^{ab}	0.05	8.28^{a}	0.20		0.01^{b}	0.00	7.72^{b}	0.27
	19	0.01^{a}	0.00	8.28^{a}	0.25		0.01^{a}	0.01	7.59^{b}	0.42
	20	0.01^{a}	0.01	8.47^{a}	0.11		0.04^{a}	0.06	7.87^{b}	0.36
	21	0.01^{a}	0.00	8.78^{a}	0.12		0.04^{a}	0.05	7.95^{b}	0.31
	22	0.01^{a}	0.01	8.19^{a}	0.09		0.03^{b}	0.01	7.38^{b}	0.16
	23	0.01^{a}	0.01	8.22^{a}	0.09		0.02^{a}	0.01	7.03^{b}	0.25
	24	0.01^{a}	0.01	8.00^{a}	0.25		0.19^{b}	0.00	6.78^{b}	0.00

*: Average of fifteen readings

$^{a\text{-}d}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

Table 4-5. Continued

P2-Air	0	22.21^{a}	0.01	0.20^{a}	0.00	P2-CO$_2$	3.75^{c}	0.39	13.96^{c}	0.29
	1	18.17^{a}	0.15	3.21^{c}	0.12		3.17^{c}	0.62	11.11^{d}	0.26
	2	14.77^{a}	0.33	5.31^{c}	0.19		2.12^{c}	0.57	9.08^{d}	0.17
	3	12.62^{c}	0.45	6.33^{c}	0.23		1.63^{d}	0.58	8.02^{d}	0.24
	4	10.67^{c}	0.56	7.01^{c}	0.25		1.12^{d}	0.61	7.53^{d}	0.24
	5	9.01^{c}	0.63	7.30^{c}	0.29		0.64^{d}	0.40	7.06^{c}	0.25
	6	7.58^{c}	0.72	7.24^{b}	0.35		0.47^{d}	0.26	6.61^{c}	0.26
	7	6.72^{c}	0.78	7.00^{c}	0.56		0.32^{b}	0.27	6.36^{d}	0.28
	8	5.09^{b}	0.67	7.29^{c}	0.33		0.16^{c}	0.05	6.21^{d}	0.26
	9	3.77^{b}	0.75	7.47^{b}	0.53		0.16^{c}	0.04	6.10^{c}	0.29
	10	2.67^{c}	0.78	7.42^{b}	0.16		0.10^{b}	0.04	5.74^{c}	0.18
	11	1.83^{b}	0.77	7.54^{b}	0.34		0.09^{c}	0.03	5.79^{c}	0.19
	12	0.96^{b}	0.75	7.24^{b}	0.15		0.13^{a}	0.12	5.42^{c}	0.31
	13	0.42^{b}	0.41	7.02^{c}	0.30		0.22^{ab}	0.16	5.36^{d}	0.40
	14	0.06	0.04	6.69^{c}	0.28		0.17	0.18	5.45^{d}	0.46
	15	0.07^{a}	0.05	6.32^{c}	0.29		0.18^{b}	0.18	5.47^{d}	0.45
	16	0.11^{b}	0.15	6.13^{c}	0.28		0.15^{b}	0.08	5.62^{d}	0.33
	17	0.08^{b}	0.08	5.97^{b}	0.39		0.13^{b}	0.05	5.79^{b}	0.32
	18	0.08^{a}	0.09	5.93^{c}	0.44		0.09^{a}	0.03	5.87^{c}	0.27
	19	0.06^{a}	0.05	6.04^{c}	0.54		0.13^{b}	0.08	6.09^{c}	0.17
	20	0.05^{ab}	0.03	6.30^{c}	0.67		0.10^{b}	0.07	6.52^{c}	0.28
	21	0.05^{a}	0.02	6.63^{c}	0.65		0.10^{b}	0.03	7.01^{c}	0.19
	22	0.03^{b}	0.01	6.25^{c}	0.29		0.07^{c}	0.01	6.48^{c}	0.00
	23	0.05^{a}	0.03	6.27^{c}	0.17		0.33^{b}	0.22	6.76^{d}	0.04
	24	0.05^{c}	0.00	6.13^{c}	0.03		0.06^{d}	0.00	6.44^{d}	0.14

*: Average of fifteen readings

$^{a\text{-}d}$: Superscripts within each treatment denote significant difference at the $p<0.05$.
Means were separated using LSD.

Table 4-6. Oxygen and carbon dioxide (%) measurements of modified atmosphere stored zucchini slices during storage for experiment II.

Treatment	Storage Time (Days)	O_2 (%)*		CO_2 (%)*		Treatment	O_2 (%)		CO_2 (%)	
		Avg.	St.dev.	Avg.	St.dev.		Avg.	St.dev.	Avg.	St.dev.
P1-Air	0	22.15^a	0.10	0.03^a	0.03	P1-CO_2	5.87^b	0.47	12.06^b	0.37
	1	19.98^a	0.50	2.42^a	0.14		2.77^b	0.63	12.15^b	0.33
	2	17.19^a	0.29	4.43^a	0.22		1.81^b	0.57	10.65^b	0.22
	3	15.38^a	0.40	5.58^a	0.26		1.31^b	0.47	9.79^b	0.20
	4	14.23^a	0.47	6.11^a	0.45		0.97^b	0.44	9.47^b	0.19
	5	12.69^a	0.52	6.86^a	0.30		0.52^b	0.38	8.82^b	0.22
	6	11.30^a	0.59	7.17^a	0.32		0.19^b	0.27	8.65^b	0.18
	7	9.81^a	0.67	7.58^a	0.32		0.07^b	0.09	8.35^b	0.18
	8	8.03^a	0.90	8.19^a	0.43		0.04^b	0.01	7.93^b	0.18
	9	5.79^a	1.21	9.04^a	0.59		0.03^c	0.01	7.65^b	0.19
	10	2.75^a	1.57	10.50^a	0.73		0.02^c	0.01	7.64^b	0.14
	11	0.46^{ab}	0.91	11.79^a	0.81		0.02^b	0.01	7.76^b	0.16
	12	0.02^a	0.01	11.71^a	0.24		0.02	0.00	8.22^b	0.22
	13	0.04^a	0.01	11.23^a	0.27		0.01^b	0.00	8.20^b	0.48
	14	0.05^a	0.01	10.58^a	0.26		0.01^b	0.00	8.26^b	0.21
	15	0.06^a	0.01	10.65^a	0.67		0.00^b	0.00	8.32^b	0.15
	16	0.05^a	0.02	10.64^a	0.50		0.00^b	0.00	8.77^b	0.13
	17	0.05^a	0.02	10.64^a	0.50		0.00^b	0.00	8.77^b	0.13

*: Average of fifteen readings

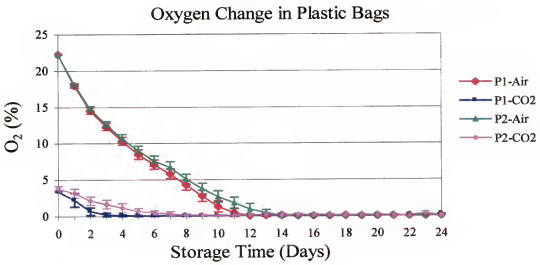
$^{a\text{-}d}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

Table 4-6. Continued

P2-Air	0	22.12^{a}	0.03	0.13^{a}	0.03	P2-CO$_2$	4.28^{c}	1.06	13.28^{c}	0.76
	1	20.10^{a}	0.40	2.12^{c}	0.14		3.29^{c}	0.37	10.94^{d}	0.19
	2	17.41^{a}	0.22	4.01^{c}	0.12		3.17^{c}	0.61	8.72^{d}	0.32
	3	15.71^{c}	0.25	4.74^{c}	0.18		2.99^{d}	0.74	7.58^{d}	0.24
	4	14.64^{c}	0.27	5.38^{c}	0.35		2.85^{d}	0.84	7.16^{d}	0.23
	5	13.24^{c}	0.35	5.68^{a}	0.27		2.61^{d}	0.97	6.88^{a}	0.19
	6	11.94^{c}	0.39	5.84^{c}	0.21		2.01^{d}	0.73	6.66^{d}	0.23
	7	10.70^{c}	0.45	6.02^{c}	0.21		1.62^{d}	0.77	6.47^{d}	0.21
	8	9.22^{c}	0.61	6.34^{c}	0.30		1.03^{d}	0.65	6.41^{c}	0.21
	9	7.47^{b}	0.89	6.70^{c}	0.48		0.60^{c}	0.59	6.33^{d}	0.25
	10	4.42^{b}	1.65	8.13^{b}	0.91		0.18^{c}	0.28	6.60^{c}	0.23
	11	1.24^{a}	1.87	9.95^{c}	1.07		0.06^{b}	0.02	6.78^{d}	0.56
	12	0.33	0.93	9.25^{c}	0.48		0.05	0.02	6.45^{d}	0.45
	13	0.07^{c}	0.02	8.91^{c}	0.71		0.06^{c}	0.03	5.89^{d}	0.37
	14	0.04^{a}	0.03	8.82^{c}	0.51		0.05^{a}	0.04	5.98^{d}	0.38
	15	0.02^{bc}	0.02	9.12^{c}	0.52		0.04^{c}	0.03	6.14^{d}	0.51
	16	0.00^{b}	0.01	9.44^{c}	0.66		0.03^{a}	0.04	6.50^{d}	0.63
	17	0.00^{b}	0.01	9.44^{c}	0.66		0.03^{a}	0.04	6.50^{d}	0.63

*: Average of fifteen readings

$^{a-d}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.



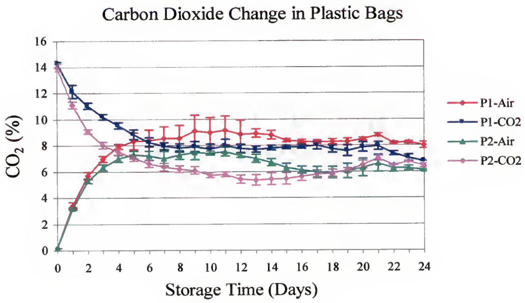


Figure 4-6. Change of oxygen and carbon dioxide in modified atmosphere stored zucchini slices over time for experiment I.

treated with CO_2. However, CO_2 levels were greater in P1 (Figure 4-7). These results were expected because fresh-cut vegetables have higher respiration rates, which increased CO_2 levels in bags flushed with air. In addition, the observed decrease in CO_2 levels of bags flushed with CO_2 was due to CO_2 permeation rate of the plastic bags.

Sensory Analysis

The average sensory scores given by panelists of all treatments over time for CA experiment, experiment I and experiment II and their standard deviations are shown in Tables 4-7, 4-8, 4-9, respectively. For color evaluation, peel and flesh color of zucchini slices stored under controlled atmosphere was rated using yellowness and greenness of peel color, and browning and discoloration of the flesh color as sensory attributes during storage for CA experiment. Texture was evaluated for hardness and crispness attributes while odor was rated for off-odor and fresh zucchini aroma attributes for CA experiment. Results from ANOVA showed that there was no significant treatment effects for preventing formation of yellow color. However, there was a significant storage time and panelist effect for yellowness ($p<0.001$). For greenness, no treatment effects were observed from statistical analysis. Overall, the sensory scores for air and CO_2 (7% and 15%) treatments were not significantly different for greenness and yellowness (Table 4-7 and Figure 4-8). On the other hand, statistically significant treatment, storage time, their interactions and panelist effect were determined on browning and discoloration of zucchini flesh color for CA experiment ($p<0.001$). Especially toward the end of the storage period, the sensory scores for air and $7\%CO_2+2\%O_2$ treated samples were significantly different than those treated with $15\%CO_2+2\%O_2$ (Table 4-7). Same results were obtained for color analysis. Especially air treated samples showed more increase of

Table 4-7. Sensory scores of controlled atmosphere storage study

Treatments	Storage Time (Days)	Sensory Scores*															
		Peel Color				Flesh Color				Texture				Odor			
		Yellowness		Greenness		Browning		Discoloration		Hardness		Crispness		Off odor		Zucchini flavor	
		Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.
Air	0	1.38	2.44	8.89	1.15	1.28	2.77	2.49	3.91	8.39	2.05	8.37	1.65	1.55	2.39	8.50	1.80
	2	1.26	1.49	7.53	2.17	1.52	2.33	2.13	2.34	6.93	2.28	6.97	2.32	1.47	1.60	6.65	2.74
	4	3.04	2.58	7.13	1.45	3.84	2.13	5.16^{a}	1.67	3.41^{a}	2.41	3.44^{a}	2.55	6.19^{a}	2.85	3.93	3.01
	6	2.05	2.67	7.34	2.14	6.08	1.40	6.88	0.94	2.98	1.34	3.31	1.67	6.96	1.56	2.66	1.66
	8	1.94	1.94	7.62	1.57	7.07^{a}	1.74	8.19^{a}	0.93	1.00^{a}	0.68	0.75	0.50	8.79^{a}	0.62	1.03^{a}	0.66
	10	0.94	0.22	8.93	0.62	8.91^{a}	0.42	9.24^{a}	0.56	0.34^{a}	0.18	0.30^{a}	0.15	9.54^{a}	0.39	0.38^{a}	0.32
	12	2.84	3.01	7.26	2.67	6.00^{a}	4.31	7.14^{ab}	3.97	0.49^{a}	0.39	0.40^{a}	0.21	9.37^{a}	0.51	0.51^{a}	0.35
$7\%CO_2+2\%O_2$	0	0.97	1.18	8.15	2.73	1.24	1.81	1.55	2.16	8.41	2.08	8.88	1.58	1.19	1.58	7.91	2.13
	2	1.28	1.61	8.17	2.04	1.43	2.16	1.99	2.32	5.68	3.06	6.15	3.12	1.65	2.23	5.87	3.58
	4	2.05	1.61	7.77	1.74	2.40	1.96	2.49^{b}	1.66	7.40^{b}	1.81	7.70^{b}	1.38	3.10^{b}	3.09	7.76	1.99
	6	1.15	1.32	8.23	1.73	3.06	1.59	2.97	1.20	7.32	1.90	6.16	3.08	4.34	2.22	3.88	1.49
	8	2.22	1.85	7.68	1.75	4.36^{b}	2.29	5.40^{b}	1.32	3.46^{b}	1.49	2.64	1.29	7.90^{a}	1.37	1.70^{a}	1.19
	10	0.35	0.24	9.40	0.35	6.25^{b}	2.78	5.97^{b}	2.57	4.71^{b}	1.02	3.76^{b}	0.93	6.35^{b}	2.24	2.80^{b}	2.03
	12	3.41	2.68	7.24	2.58	7.01	2.19	7.97^{a}	0.99	1.15^{a}	0.55	1.00^{a}	0.72	8.34^{b}	0.89	0.84^{a}	0.48
$15\%CO_2+2\%O_2$	0	1.40	1.38	8.05	1.96	1.18	1.83	1.55	2.07	8.13	1.81	8.26	2.03	1.40	1.62	7.57	3.02
	2	1.27	1.33	8.32	1.80	1.24	1.37	1.88	1.29	5.90	2.24	6.77	1.57	1.45	1.79	8.04	1.71
	4	2.07	1.52	7.35	2.02	2.28	2.00	2.32^{b}	2.08	8.49^{b}	1.05	7.08^{b}	2.12	1.90^{b}	1.92	7.62	1.26
	6	1.46	1.60	8.33	1.80	2.56	3.28	1.46	1.45	7.87	1.92	7.11	1.65	1.41	1.20	6.71	3.32
	8	2.50	1.89	7.31	1.30	4.05^{b}	2.04	4.03^{b}	2.10	5.44^{c}	1.47	5.12	2.04	5.35^{b}	1.25	4.77^{b}	1.16
	10	0.71	0.91	9.32	0.84	5.73^{b}	2.62	7.23^{b}	1.68	4.37^{b}	0.87	4.00^{b}	1.40	7.88^{b}	1.41	0.80^{a}	0.38
	12	2.31	1.80	7.56	1.88	3.96	1.91	4.59^{b}	1.70	4.34^{b}	1.35	4.30^{b}	1.60	6.46^{c}	1.23	3.13^{b}	2.23

Avg.*: Average of eight readings

St. dev. : Standard deviation of eight readings

$^{a\text{-}c}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

Table 4-8. Sensory Scores for first experiment of modified atmosphere storage study

Treatments	Storage Time (Days)	Sensory Scores*							
		Odor				Color			
		Off-odor		Fresh zucchini aroma		Whiteness-yellowness		Degree of transparency	
		Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.
P1-Air	0	1.55^{a}	2.06	12.37	2.70	3.02	2.18	1.06^{ab}	1.70
	3	2.06	3.19	10.60	4.07	2.62^{a}	2.53	0.88	1.88
	6	2.17^{ab}	1.78	9.35	3.70	3.58	2.36	1.40	1.69
	8	1.77	1.50	9.56^{b}	4.30	3.79	2.47	1.40^{ab}	1.19
	10	2.15	2.29	9.91	4.20	3.58	2.46	2.41	2.85
	13	4.06^{a}	3.50	10.21^{a}	3.42	4.83^{ab}	2.86	2.00	1.85
	15	3.07^{ab}	3.36	10.82^{a}	3.62	4.79	2.66	2.42	3.07
	17	3.00^{ab}	2.73	9.07	3.12	5.19	2.82	3.20	3.09
	22	5.00	3.63	7.51^{a}	4.47	4.09^{b}	2.93	2.56^{bc}	2.30
	24	5.25^{b}	4.68	9.41^{a}	4.08	4.76^{bc}	3.63	3.66	3.94
P1-CO_2	0	1.14^{b}	1.35	12.11	2.33	3.27	2.68	0.96^{b}	1.13
	3	2.24	3.40	11.59	3.42	2.76^{a}	2.55	1.07	1.63
	6	2.88^{a}	2.38	10.39	4.12	3.40	2.36	1.44	1.25
	8	2.14	2.00	11.73^{a}	3.18	3.69	2.43	1.22^{b}	1.16
	10	3.06^{a}	2.75	10.23	4.01	3.30	2.50	1.98	2.54
	13	4.21^{a}	3.60	9.70^{a}	3.76	4.12^{b}	2.18	2.00	1.47
	15	3.49^{a}	2.93	9.87^{a}	3.98	4.17	2.79	2.53	3.30
	17	3.70^{a}	2.86	9.07	3.79	4.41	2.97	2.46	2.58
	22	5.93	2.73	7.32^{ab}	3.94	3.45^{b}	2.83	2.18^{c}	2.47
	24	7.78^{a}	4.40	7.33^{b}	4.49	4.44^{c}	3.05	3.65	4.00
P2-Air	0	1.42^{ab}	1.57	12.57	2.08	3.25	2.23	1.27^{a}	2.09
	3	2.45	3.14	10.34	3.72	2.34^{ab}	2.27	1.22	2.21
	6	2.04^{b}	2.07	9.69	3.84	3.67	2.32	1.29	1.18
	8	2.32	2.41	9.61^{b}	3.70	4.12	2.40	1.89^{a}	1.71
	10	2.18^{b}	2.03	10.16	3.68	3.57	2.92	2.21	2.86
	13	3.54^{b}	2.44	9.27^{b}	3.97	5.05^{a}	2.61	2.49	1.86
	15	2.33^{b}	1.81	9.52^{b}	4.22	4.82	3.13	2.65	3.51
	17	2.06^{c}	2.31	7.98	4.22	4.67	2.92	3.01	3.31
	22	6.00	3.55	6.68^{bc}	4.06	6.05^{a}	3.56	3.88^{ab}	3.20
	24	5.42^{b}	4.09	9.74^{a}	3.97	5.84^{b}	3.79	4.50	4.16
P2-CO_2	0	0.97^{b}	1.24	12.72	2.09	3.15	2.02	1.03^{ab}	1.62
	3	2.30	3.14	10.77	3.95	1.98^{b}	2.11	0.86	1.70
	6	1.82^{b}	1.48	10.00	3.77	3.52	2.40	1.20	1.25
	8	2.14	1.74	10.84^{a}	3.74	3.90	2.46	1.52^{ab}	1.47
	10	2.98^{a}	2.60	10.13	3.99	3.68	2.67	2.22	2.68
	13	3.81^{a}	3.22	9.49^{a}	4.18	5.19^{a}	2.75	2.03	1.55
	15	3.08^{ab}	2.77	9.55^{ab}	4.02	4.66	2.83	2.75	3.47
	17	2.52^{bc}	1.99	9.52	3.44	4.87	2.70	2.82	3.14
	22	6.12	3.82	6.01^{c}	4.20	6.65^{a}	3.35	4.42^{a}	3.21
	24	5.69^{b}	4.01	8.80^{ab}	4.22	7.13^{a}	4.03	5.10	4.05

*: Average of 30 readings from both replications St.dev. : Standard deviation of 30 readings from both replications.

$^{a-c}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

Table 4-8. Continued

Treatments	Storage Time (Days)	Sensory Scores*							
		Surface				Texture			
		Surface breakdown		Surface moisture		Hardness-Softness		Crispness	
		Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.
P1-Air	0	1.02	1.46	1.63^{ab}	1.91	1.91	2.11	11.05	3.40
	3	1.55	3.10	1.97	2.63	4.50	3.23	10.74	3.60
	6	1.72	2.44	2.59	2.49	4.91	3.04	9.92	3.38
	8	1.43	1.11	2.51	2.74	4.30	2.39	9.67^{ab}	3.18
	10	2.80	2.92	2.88	2.56	4.11	2.33	10.42	2.68
	13	2.23	1.58	3.90	2.69	5.58^{a}	3.39	9.99^{ab}	2.41
	15	1.84	1.75	3.03	2.54	5.59^{ab}	2.73	10.21	2.49
	17	3.02^{a}	2.76	3.39	2.48	5.65	2.82	9.86^{b}	2.86
	22	2.94^{b}	2.79	3.60^{b}	3.20	5.34	2.89	8.99	3.61
	24	3.10^{a}	2.70	4.03^{b}	3.74	5.38^{c}	3.08	9.69^{a}	3.82
P1-CO_2	0	1.05	1.76	1.72^{a}	1.70	1.72	1.75	10.94^{b}	3.28
	3	1.75	3.06	2.32	2.98	4.58	3.33	9.67	4.01
	6	1.72	2.38	2.80	2.87	4.75	2.52	9.54	3.36
	8	1.32	0.98	2.38	2.74	4.96	3.02	8.90^{b}	3.43
	10	2.24	2.86	2.97	2.36	4.53	2.89	10.23	2.96
	13	2.14	1.67	3.60	2.32	5.65^{a}	2.88	9.37^{b}	2.21
	15	1.79	1.71	2.65	1.94	5.83^{a}	2.87	9.30	3.39
	17	1.86^{b}	1.63	2.80	1.93	5.82	2.63	9.95^{b}	2.46
	22	2.32^{b}	2.23	3.24^{b}	2.56	5.29	3.45	8.30	3.34
	24	2.79^{a}	2.27	3.92^{b}	2.67	6.92^{a}	3.80	8.23^{b}	3.37
P2-Air	0	1.46	2.39	1.61^{ab}	2.03	1.88	1.58	11.60^{ab}	2.72
	3	1.89	3.51	1.97	3.00	4.55	3.11	10.02	3.47
	6	1.66	2.06	2.57	2.51	4.47	2.88	10.31	2.61
	8	1.79	1.74	2.28	2.32	5.28	3.35	9.76^{a}	3.26
	10	1.73	1.91	2.89	2.66	4.26	3.13	10.81	2.84
	13	2.28	1.80	3.32	2.32	4.32^{b}	2.33	10.57^{a}	2.46
	15	2.37	2.75	3.49	2.92	5.08^{b}	2.72	10.22	3.11
	17	1.98^{b}	2.08	2.67	2.25	5.42	2.36	10.77^{a}	2.56
	22	4.72^{a}	3.69	6.02	4.27	5.52	3.01	9.18	3.52
	24	3.94^{a}	3.25	5.44^{ab}	4.08	5.72^{bc}	3.05	10.15^{a}	3.17
P2-CO_2	0	0.93	1.76	1.71^{b}	1.85	1.69	1.52	11.73^{a}	2.67
	3	1.43	3.00	1.54	2.46	4.60	3.36	9.86	3.49
	6	1.53	2.04	2.53	2.74	4.73	2.77	9.75	3.13
	8	1.76	1.46	2.68	2.56	4.80	2.67	9.23^{ab}	3.48
	10	2.78	2.51	3.03	2.75	4.36	2.68	10.45	2.96
	13	1.97	1.60	3.54	2.08	5.33^{a}	2.66	9.61	2.44
	15	2.35	2.28	2.96	2.26	5.36^{ab}	2.55	9.78	2.93
	17	1.82^{b}	1.84	2.60	2.00	5.19	2.32	10.41^{ab}	2.72
	22	5.55^{a}	3.67	7.27^{a}	3.97	6.12	2.82	8.42	3.17
	24	5.28^{b}	4.03	6.77^{a}	4.09	6.54^{ab}	3.86	9.00^{ab}	3.99

Avg*: Average of 30 readings from both replications

St. dev. : Standard deviation of 30 readings from both replications

$^{a-c}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

Table 4-9. Sensory scores for second experiment of modified atmosphere storage study

Treatments	Storage Time (Days)	Sensory Scores*							
		Odor				Color			
		Off-odor		Fresh zucchini aroma		Whiteness-yellowness		Degree of transparency	
		Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.
P1-Air	0	1.53	3.00	12.93	2.42	1.63	2.03	0.33	0.46
	3	0.41^{b}	0.55	13.84	1.35	1.32^{ab}	1.88	0.24	0.34
	6	1.13	2.75	13.14	2.23	1.89	1.99	0.52^{b}	0.50
	8	1.14^{a}	1.63	12.08	2.49	2.83^{a}	3.00	1.34^{a}	1.36
	10	2.10^{a}	2.19	11.68	3.52	3.37^{a}	2.69	2.11^{a}	2.13
	13	9.72^{a}	4.73	3.17^{a}	3.60	9.94^{a}	3.87	9.85^{a}	4.32
	15	11.35^{a}	3.87	1.92^{a}	2.78	10.75^{a}	3.87	10.92^{a}	4.05
	17	13.02^{a}	2.61	2.03	3.57	12.50^{a}	3.15	13.25^{a}	2.21
P1-CO_2	0	1.14	2.72	13.41	1.86	1.50	1.78	0.32	0.47
	3	0.56^{ab}	1.07	13.80	1.41	1.29^{b}	1.96	0.23	0.32
	6	0.68	1.27	12.87	2.52	1.66	1.92	0.46^{b}	0.52
	8	0.83^{ab}	1.23	12.88^{b}	2.52	2.22^{b}	2.58	0.74^{b}	0.87
	10	1.15^{b}	1.35	12.62	2.33	2.33^{b}	2.29	1.05^{b}	1.06
	13	2.37^{c}	2.42	9.91^{c}	3.81	2.74^{c}	2.20	1.69^{c}	2.27
	15	4.75^{b}	4.05	6.95^{b}	4.54	5.18^{b}	3.33	4.27^{b}	3.57
	17	11.21^{b}	3.53	3.40	4.04	9.30^{b}	4.18	10.24^{b}	3.68
P2-Air	0	1.50	2.83	13.00	2.60	1.75	2.27	0.43	0.69
	3	0.64^{a}	1.16	13.61	1.63	1.48^{b}	2.40	0.38	0.59
	6	0.66	1.10	12.78	2.82	1.67	1.98	0.44^{b}	0.44
	8	0.66^{b}	1.10	12.78^{b}	2.40	2.08^{b}	2.43	0.94^{ab}	0.98
	10	1.37^{b}	1.87	12.43	2.65	2.64^{ab}	2.30	1.28^{b}	1.24
	13	7.71^{b}	4.95	4.83^{b}	4.38	6.62^{ab}	3.98	6.57^{b}	4.57
	15	12.10^{a}	3.07	1.74^{a}	2.26	11.40^{a}	3.40	11.83^{a}	3.44
	17	12.96^{a}	2.87	1.88	3.49	12.96^{a}	2.74	13.85^{a}	1.50
P2-CO_2	0	1.52	3.14	13.25	1.98	1.75	2.15	0.41	0.60
	3	0.66^{a}	1.14	13.58	1.57	1.52^{a}	2.30	0.35	0.47
	6	0.93	1.71	12.72	2.87	1.72	1.72	0.79^{a}	0.85
	8	0.76^{b}	1.35	12.72^{b}	2.46	2.07^{b}	2.30	0.96^{ab}	1.19
	10	1.47^{ab}	1.61	11.55	2.57	2.56^{b}	2.13	1.08^{b}	0.92
	13	2.84^{c}	3.06	9.53^{c}	3.80	3.59^{c}	2.98	3.08^{c}	3.14
	15	4.29^{b}	4.21	7.78^{b}	4.34	4.59^{b}	2.62	3.25^{b}	2.47
	17	10.00^{b}	4.49	3.39	4.19	10.26^{b}	3.89	10.08^{b}	3.80

*:Avg: Average of 30 readings from both replications

*:St. dev. : Standard deviation of 30 readings from both replications

$^{a\text{-}c}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

Table 4-9. Continued

Treatments	Storage Time (Days)	Sensory Scores							
		Surface				Texture			
		Surface breakdown		Surface moisture		Hardness-Softness		Crispness	
		Avg	St.dev.	Avg	St.dev.	Avg	St.dev.	Avg	St.dev.
P1-Air	0	0.37	0.45	3.91	4.09	3.29^a	3.81	12.53	2.45
	3	0.29^b	0.44	2.47^b	2.80	2.09	2.04	12.34	2.43
	6	1.01^a	1.25	2.86	2.36	3.22^{ab}	3.22	11.96	2.76
	8	2.27^a	3.35	3.34^a	2.65	3.37	2.77	11.99	2.37
	10	2.65	2.62	5.25^a	4.05	4.18^a	3.39	11.19^a	3.24
	13	10.46^a	4.13	11.84^a	3.37	10.24^a	5.47	2.06^a	3.10
	15	11.80^a	3.59	12.51^a	3.03	11.06^a	5.22	1.48^a	2.41
	17	13.80^a	2.02	13.89^a	1.68	13.40^a	3.75	0.66^a	1.98
P1-CO_2	0	0.32	0.45	3.71	4.12	3.08^{ab}	3.58	12.60	2.28
	3	0.28^b	0.40	2.98^a	2.82	2.04	2.18	12.53	2.44
	6	0.54^b	0.53	2.47	2.35	3.11^{ab}	3.25	12.05	2.72
	8	1.52^b	3.39	2.68^b	2.71	3.17	3.30	12.15	2.83
	10	1.63	2.61	3.37^b	3.08	2.88^b	2.69	12.00^b	2.53
	13	2.03^c	2.64	5.20^c	3.40	4.48^c	3.56	10.58^b	3.48
	15	4.38^b	3.65	7.73^b	3.80	7.38^b	3.56	7.53^b	3.82
	17	9.31^c	4.75	11.66^b	2.95	11.46^b	3.85	1.85^b	2.11
P2-Air	0	0.45	0.67	3.74	4.02	2.82^b	3.14	12.46	2.49
	3	0.39^a	0.55	2.47^b	2.76	2.13	2.52	12.31	2.84
	6	0.50^b	0.48	2.66	2.43	2.89^b	2.75	11.85	3.27
	8	1.80^b	3.46	2.88^{ab}	2.47	2.87	2.78	12.18	2.81
	10	1.92	2.65	3.73^b	2.72	3.42^{ab}	3.13	11.77^{ab}	2.45
	13	7.70^b	4.79	9.75^b	3.99	7.24^b	5.16	4.89^c	4.61
	15	12.17^a	3.47	13.04^a	2.72	11.67	5.20	1.54^a	3.06
	17	14.10	1.27	14.33^a	0.84	13.57	3.73	0.82^a	2.69
P2-CO_2	0	0.41	0.60	3.75	4.02	2.82^b	3.08	12.19	3.35
	3	0.41^a	0.61	2.54^b	2.80	2.30	2.54	12.24	2.58
	6	0.89^{ab}	1.11	2.39	2.29	3.42	3.40	11.89	2.86
	8	1.74^b	3.40	2.60^b	2.56	3.11	3.16	12.26	2.66
	10	1.76	2.47	3.76^b	2.94	3.44^{ab}	3.05	11.50^{ab}	2.86
	13	3.26^c	3.14	5.83^c	4.32	5.61^c	3.58	9.71^b	3.91
	15	3.31^b	2.40	6.86^b	3.89	5.43^c	2.86	8.83^b	3.46
	17	10.68^b	3.68	11.43^b	3.07	10.57^c	4.17	2.21^b	2.95

*: Average of 30 readings from both replications

St. dev. : Standard deviation of 30 readings from both replications

$^{a-c}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

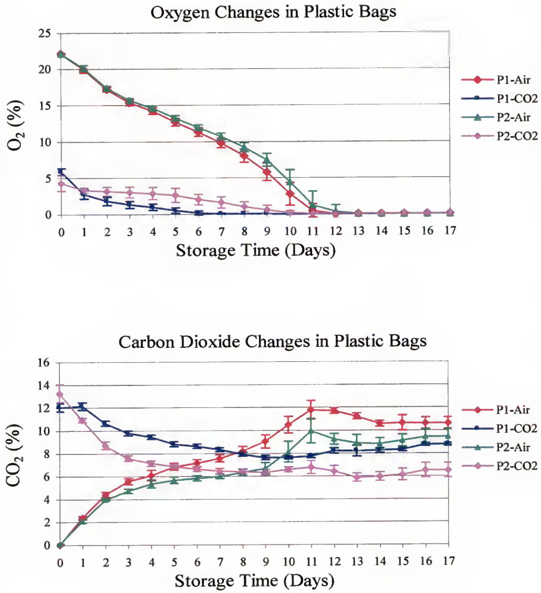
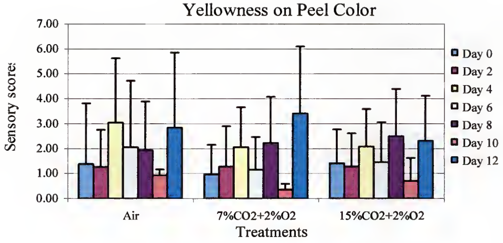


Figure 4-7. Change of oxygen and carbon dioxide in modified atmosphere stored zucchini slices over time for experiment II.



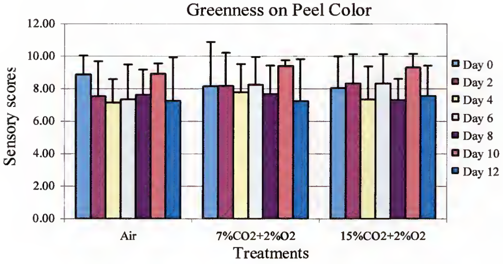
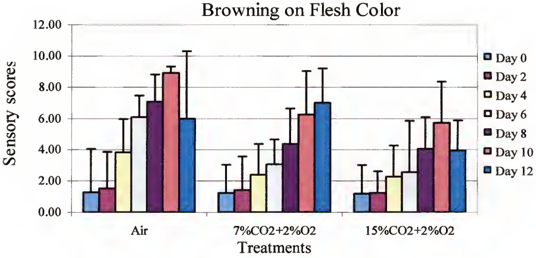


Figure 4-8. Average sensory scores of yellowness and greenness on peel color of zucchini slices stored under controlled atmosphere over time for controlled atmosphere experiment. Lines above bars denote standard errors.

browning and discoloration than CO_2 treated samples, with storage time. Best color preservation was obtained with 15%CO_2 + 2%O_2 (Figure 4-9). Hardness and crispness as textural characteristics showed significant treatment, storage time, their interaction and panelist effects for controlled atmosphereexperiment ($p<0.001$). The sensory scores for all treatments were significantly different from each other, especially toward the end of the storage (Table 4-7). Figure 4-10 showed that air treated samples lost their crispness and hardness after day 10. Best crispness and hardness were observed from 15%CO_2 +2% O_2 treated samples followed by 7%CO_2 +2% O_2 treated samples. The odor sensory scores given to samples treated with air and both 7 and 15%CO_2 were significantly different from each other ($p<0.001$). As the storage time increased, off odor of zucchini slices treated with air and CO_2 increased, while fresh zucchini aroma decreased (Figure 4-11). This was expected since when the microbial load exceeded 10^7 cfu/g the product started to have off odors.

During experiment I, similar sensory attributes used for CA experiment were utilized for odor, texture, color evaluation as well as surface evaluation by 15 panelists. In addition, surface moisture and surface breakdown attributes were added to sensory analysis as an indicator of overall quality evaluation. The average sensory scores of P1-Air, P1-CO_2, P2-Air and P2-CO_2 treatments and their standard deviations are presented in Table 4-8 and Figures 4-12 to 4-15. Off odor sensory scores for P1-CO_2 are significantly different from those of samples treated with P1-Air, P2-Air and P2-CO_2 especially towards the end of the storage period. Other treatments did not show any difference from each other. Air flushed samples in bag 1and bag 2 were expected to develop more off odor than CO_2 flushed samples. There was no significant difference



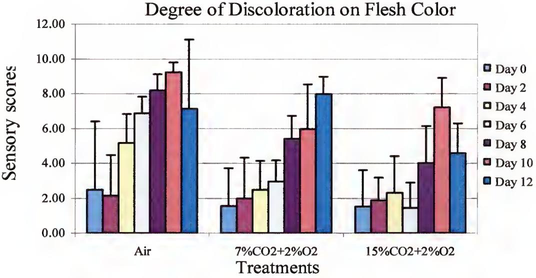
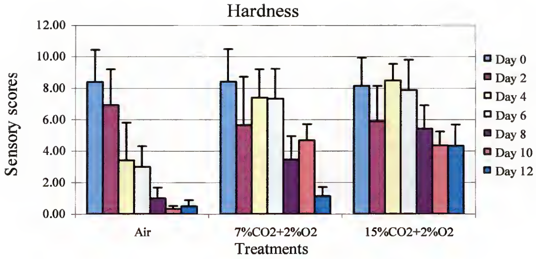


Figure 4-9. Average sensory scores of browning and degree of transparency on flesh color of zucchini slices stored under controlled atmosphere over time for controlled atmosphere experiment. Lines above bars denote standard errors.



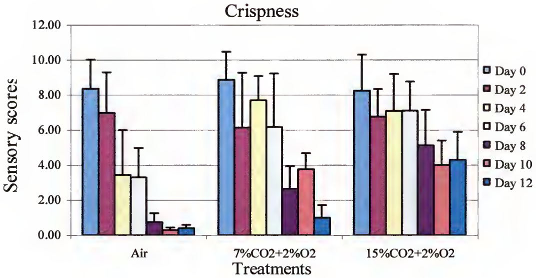
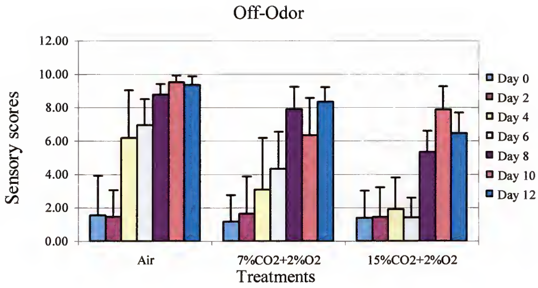


Figure 4-10. Average sensory scores of hardness and crispness as textural characteristics of zucchini slices stored under controlled atmosphere over time for controlled atmosphere experiment. Lines above bars denote standard errors.



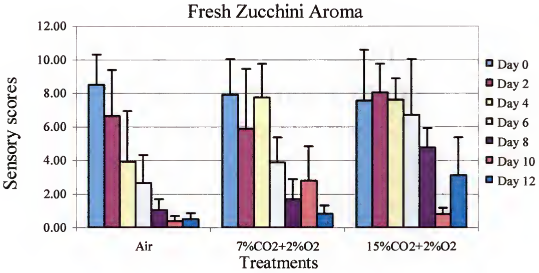
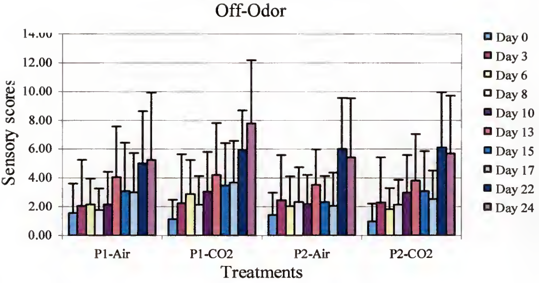


Figure 4-11. Average sensory scores of off odor and fresh zucchini aroma as odor characteristics of zucchini slices stored under controlled atmosphere over time for controlled atmosphere experiment. Lines above bars denote standard errors.



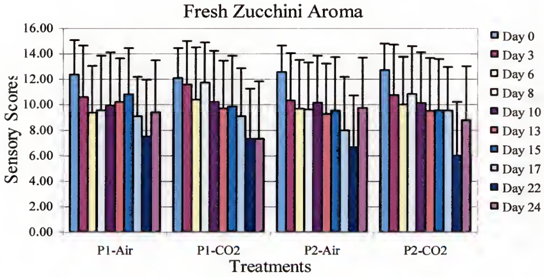
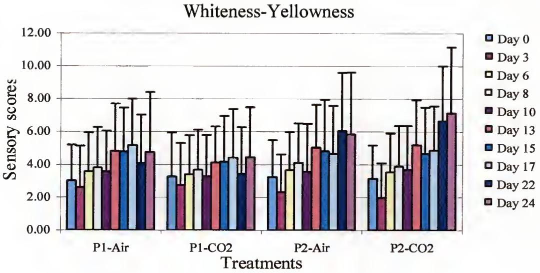


Figure 4-12. Average sensory scores of off odor and fresh zucchini aroma as odor characteristics of zucchini slices stored under modified atmosphere over time for experiment I. Lines above bars denote standard errors.



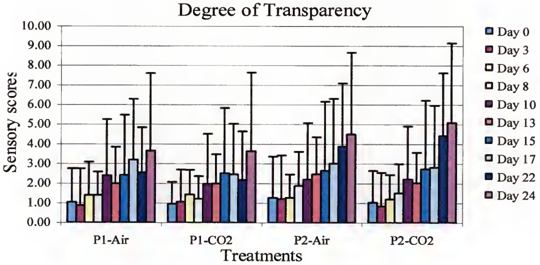
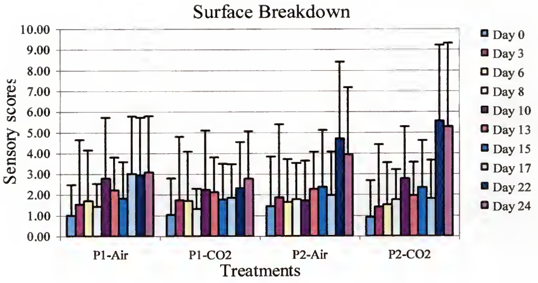


Figure 4-13. Average sensory scores of whiteness-yellowness and degree of transparency as color characteristics of zucchini slices stored under modified atmosphere over time for experiment I. Lines above bars denote standard errors.



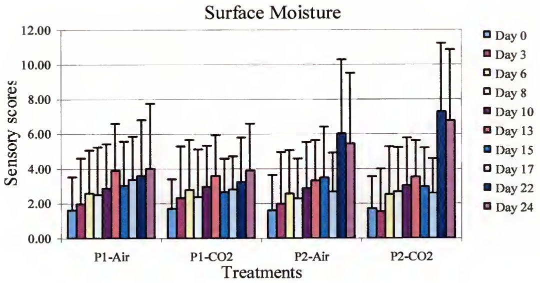
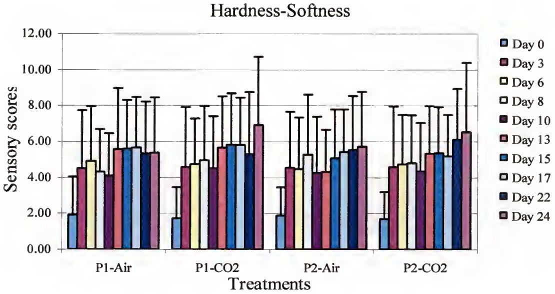


Figure 4-14. Average sensory scores of surface breakdown and surface moisture as surface characteristics of zucchini slices stored under modified atmosphere over time for experiment I. Lines above bars denote standard errors.



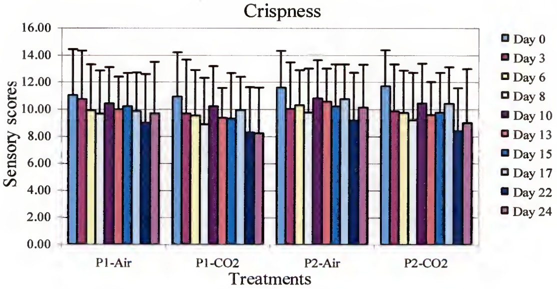
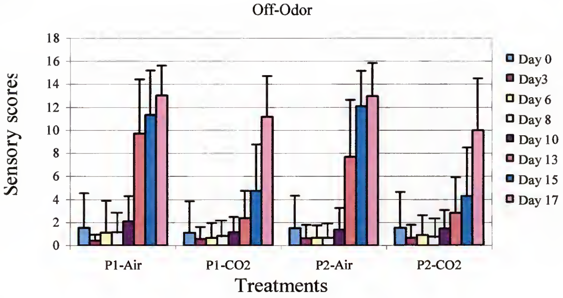


Figure 4-15. Average sensory scores of hardness and crispness as textural characteristics of zucchini slices stored under modified atmosphere over time for experiment I. Lines above bars denote standard errors.

between treatments on fresh zucchini aroma although there was a significant difference of storage time, panelist, and their interaction. No significant difference was observed on replication, either. As expected, fresh zucchini aroma decreased with time due to aging and physiological changes of product. Figure 4-12 indicated that while P1-CO_2 treatment declined gradually up to day 24, other treatments leveled off on the last day of storage. This can be due to use of different samples at each sampling day. Color changes from white to yellow were observed on zucchini slices stored under different MA and plastic bags. Statistically significant difference for all treatments was obtained ($p<0.001$) (Table 4-8 and Figure 4-13). There was also significant storage time, panelists, and interaction of treatment, storage time and panelist effects. Degree of transparency was used as an indicator of decay of the product. Zucchini samples flushed with CO_2 in bag 2 showed the greatest overall decay followed by samples flushed with air in bag 2. Lowest degree of transparency was obtained for samples flushed with CO_2 in bag 1. Figure 4-13 shows that the difference seen in the degree of transparency among the treatments was due to last two sampling days. From day 0 to day 17 differences were not apparent. Results obtained from surface breakdown and surface moisture were similar (Figure 4-14). There was a significant treatment and storage time effect on both attributes. Highest moisture and surface breakdown was observed from P2-CO_2 followed by P2-Air treatment ($p<0.001$) whereas it was medium for air treated bags and lowest for P1-CO_2. Sensory scores during last two sampling days for P2-CO_2 were high and this might have been the result of early decrease of CO_2 levels in these plastic bags. Except for the last day, no differences among the four treatment groups were detected for changes from hardness to softness (Figure 4-15). However, at day 24 P1-CO_2 showed greater changes than others. These results also agreed with the values gathered from maximum shear force for experiment I (Figure 4-4). Same results were observed for crispness.

During experiment II, the average sensory scores given by 15 panelists for all treatments and their standard deviations was shown in Table 4-9. Figure 4-16 shows the increase in off odor and decrease in fresh zucchini aroma for all treatments over storage time. The average sensory scores for off odor and fresh zucchini aroma for P1-Air followed by P2-Air are significantly different from P1-CO_2 and P2-CO_2 ($p<0.001$). Formation of off odor and disappearance of fresh zucchini aroma were high by day 13 especially on air treated samples in bags 1 and 2. Changes in yellow color formation and increasing degree of transparency were same and significant for all treatments ($p<0.001$), and increased with time (Figure 4-17). There was a significant difference between samples flushed with air in both bag 1and 2 and samples flushed with CO_2 in bags. There was no difference between P1-CO_2 and P2-CO_2 treatments. These prevented an adverse influence on product quality on color. Surface breakdown and surface moisture change had similar increasing trends with storage time. Overall there was a significant difference between treatments ($p<0.001$). Statistically there were no significant difference for both P1-CO_2 and P2 CO_2 treatments even though there was significant difference between P1-Air and P2-Air. Unlike air treated samples in both bags1 and 2, CO_2 treated samples in those bags showed less surface breakdown and surface moisture (Figure 4-18). Textural changes were observed by the decrease in hardness and crispness over time. The sensory scores for P1-Air and P2-Air were significantly different from P1-CO_2 and P2-CO_2 treatments ($p<0.001$). These delayed adverse textural changes on zucchini slices. There was a slight difference on formation of softness and decrease in crispness between P1-Air



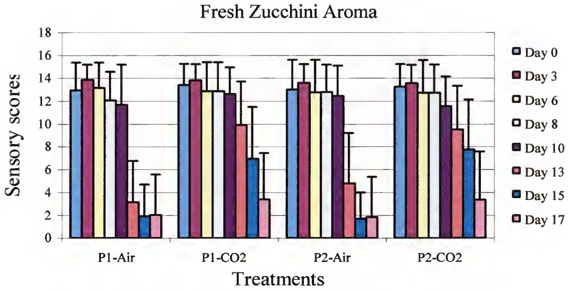
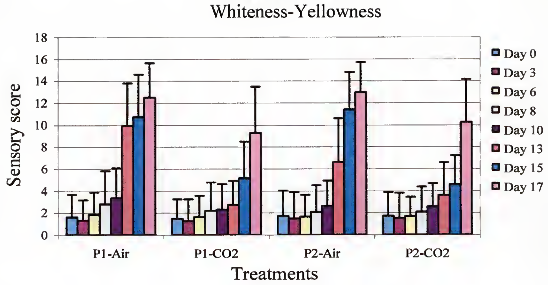


Figure 4-16. Average sensory scores of off odor and fresh zucchini aroma as odor characteristics of zucchini slices stored under modified atmosphere over time for experiment II. Lines above bars denote standard errors.



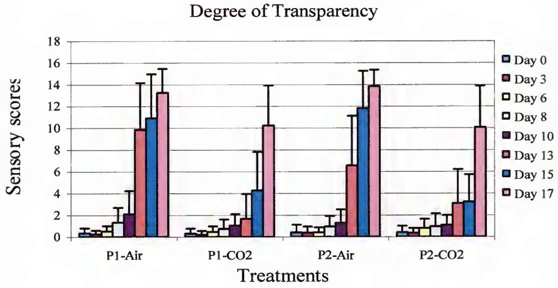
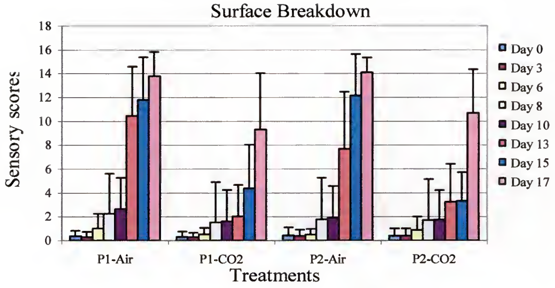


Figure 4-17. Average sensory scores of whiteness-yellowness and degree of transparency as color characteristics of zucchini slices stored under modified atmosphere over time for experiment II. Line above bars denote standard errors.



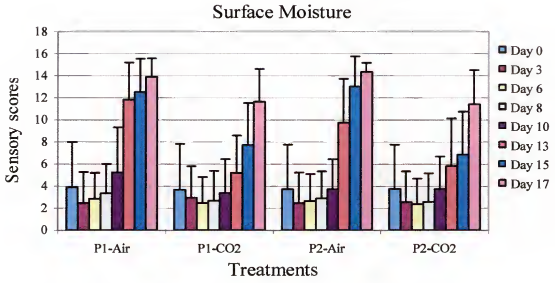


Figure 4-18. Average sensory scores of surface breakdown and surface moisture as surface characteristics of zucchini slices stored under modified atmosphere over time for experiment II. Lines above bars denote standard errors.

and P2-Air samples. They both had an adverse effect on textural quality (Figure 4-18 and 4-19).

Overall, as the storage time increased, gradual increases of off odor, degree of transparency and yellow color appearance, softness, surface breakdown, surface moisture and loss of fresh zucchini aroma were observed. These were more pronounced for air treated samples, and minimal effect of package type was detected. CO_2 treatment maintained quality better than air. During experiment I, shelf life was extended to 24 days. Shelf life of the product was about 17 days during experiment II because different varieties were used. For CA experiment, experiments I and II, water soaked areas did not develop until last two days of storage; however, the cut surface became discolored (yellow-brown), which probably was due to natural deterioration. Tissues began to deteriorate and decay shortly after development of water soaked areas or discoloration. Similar results were reported by Izumi and Watada (1995).

Color Analysis

Zucchini slices stored in different modified atmospheres can be differentiated by looking at the color changes during storage. From 512-color block data, 48 color blocks for CA experiment, 30 color blocks for experiment I and 31 color blocks for experiment II were used. These were present in air and gas combinations treatments at levels higher than 2% of total area of the slices (Table 4-10, 4-11 and 4-12).

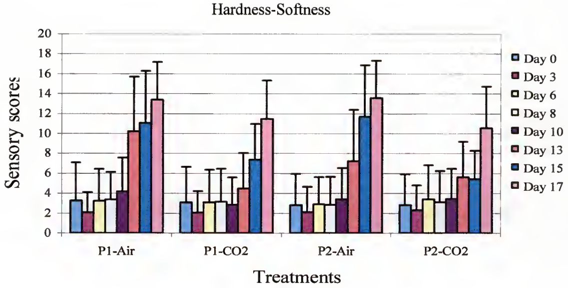
From the 48 color blocks for CA experiment (Table 4-10), only 9 most important color blocks for air treatment (425, 433, 496, 505, 506, 507, 508, 509 and 510) and $7\%CO_2 + 2\%O_2$ (152, 224, 441,496, 505, 506, 507, 508, 509 and 510) and 6 most important color blocks for $15\% CO_2 + 2\% O_2$ (505, 506, 507, 508, 509 and 510) were

Table 4-10. Color blocks for controlled atmosphere experiment.

Block #	R	G	B	L*	a*	b*	NBS Name	NBS #
8	16	48	16	9.82	-18.21	12.23	very dark yellowish green	138
16	16	80	16	23.26	-32.19	26.67	very deep yellowish green	133
80	48	80	16	24.44	-22.8	28.09	dark olive green	126
81	48	80	48	24.68	-20.37	14.97	very dark yellowish green	138
88	48	112	16	36.58	-37.47	37.02	deep yellowish green	132
152	80	112	16	38.39	-24.37	39.14	moderate olive green	125
153	80	112	48	38.52	-23.12	30.27	moderate olive green	125
160	80	144	16	49.63	-40.00	47.01	strong yellowish green	131
216	112	112	16	41.41	-7.38	42.62	moderate olive	107
224	112	144	16	51.76	-25.67	49.48	strong yellow green	117
225	112	144	48	51.84	-24.9	43.22	strong yellow green	117
226	112	144	80	52.07	-22.82	30.06	moderate yellow green	120
232	112	176	16	62.36	-41.63	56.71	strong yellow green	117
233	112	176	48	62.42	-40.98	51.94	strong yellow green	117
288	144	144	16	54.79	-9.13	52.93	light olive	106
296	144	176	16	64.66	-26.93	59.36	strong yellow green	117
297	144	176	48	64.72	-26.41	54.73	strong yellow green	117
298	144	176	80	64.88	-24.97	44.12	strong yellow green	117
305	144	208	48	74.84	-42.48	62.49	vivid yellow green	115
360	176	176	16	67.67	-10.81	62.78	strong greenish yellow	99
361	176	176	48	67.72	-10.39	58.33	moderate greenish yellow	102
368	176	208	16	77.19	-28.18	68.91	brilliant yellow green	116
369	176	208	48	77.23	-27.8	65.35	brilliant yellow green	116
370	176	208	80	77.36	-26.74	56.72	brilliant yellow green	116
378	176	240	80	87.08	-42.83	65.2	vivid yellow green	115
426	208	176	80	71.51	6.80	52.7	strong yellow	84
432	208	208	16	80.16	-12.44	72.28	strong greenish yellow	99
433	208	208	48	80.2	-12.12	68.84	strong greenish yellow	99
434	208	208	80	80.32	-11.24	60.46	strong greenish yellow	99
435	208	208	112	80.53	-9.66	48.00	moderate greenish yellow	102
440	208	240	16	89.4	-29.44	78.19	vivid yellow green	115
441	208	240	48	89.43	-29.14	75.36	brilliant yellow green	116
442	208	240	80	89.53	-28.33	68.25	brilliant yellow green	116
443	208	240	112	89.71	-26.85	57.25	brilliant yellow green	116
444	208	240	144	89.98	-24.62	43.53	light yellow green	119
445	208	240	176	90.35	-21.59	28.21	light yellow green	119
490	240	176	80	75.69	22.45	57.99	strong orange	50
497	240	208	48	83.71	3.76	72.9	brilliant yellow	83
498	240	208	80	83.81	4.48	64.81	brilliant yellow	83
499	240	208	112	84.01	5.79	52.66	light yellow	86
505	240	240	48	92.37	-13.77	78.78	brilliant greenish yellow	98
506	240	240	80	92.47	-13.08	71.86	brilliant greenish yellow	98
507	240	240	112	92.63	-11.83	61.09	brilliant greenish yellow	98
508	240	240	144	92.89	-9.93	47.57	light greenish yellow	101
509	240	240	176	93.24	-7.34	32.41	pale greenish yellow	104
510	240	240	208	93.71	-4.03	16.39	yellow white	92
511	240	240	240	94.29	0.00	0.00	white	263

Table 4-11. Color blocks for experiment I

Block #	R	G	B	L*	a*	b*	NBS Name	NBS #
81	48	80	48	24.68	-20.37	14.97	very dark yellowish green	138
152	80	112	16	38.39	-24.37	39.14	moderate olive green	125
153	80	112	48	38.52	-23.12	30.27	moderate olive green	125
154	80	112	80	38.88	-19.8	14.04	dark yellowish green	137
160	80	144	16	49.63	-40	47.01	strong yellowish green	131
161	80	144	48	49.72	-39.02	40.56	strong yellowish green	131
162	80	144	80	49.97	-36.4	27.14	strong yellowish green	131
218	112	112	80	41.85	-4.11	18.36	grayish olive	110
224	112	144	16	51.76	-25.67	49.48	strong yellow green	117
225	112	144	48	51.84	-24.9	43.22	strong yellow green	117
226	112	144	80	52.07	-22.82	30.06	moderate yellow green	120
227	112	144	112	52.5	-19.17	13.36	moderate yellowish green	136
233	112	176	48	62.42	-40.98	51.94	strong yellow green	117
234	112	176	80	62.6	-39.23	41.1	strong yellowish green	131
235	112	176	112	62.92	-36.1	26.22	strong yellowish green	131
297	144	176	48	64.72	-26.41	54.73	strong yellow green	117
298	144	176	80	64.88	-24.97	44.12	strong yellow green	117
299	144	176	112	65.18	-22.4	29.45	moderate yellow green	120
371	176	208	112	77.58	-24.84	43.99	brilliant yellow green	116
372	176	208	144	77.92	-21.98	28.81	light yellow green	119
443	208	240	112	89.71	-26.85	57.25	brilliant yellow green	116
444	208	240	144	89.98	-24.62	43.53	light yellow green	119
445	208	240	176	90.35	-21.59	28.21	light yellow green	119
446	208	240	208	90.84	-17.73	12.09	very light yellowish green	134
506	240	240	80	92.47	-13.08	71.86	brilliant greenish yellow	98
507	240	240	112	92.63	-11.83	61.09	brilliant greenish yellow	98
508	240	240	144	92.89	-9.93	47.57	light greenish yellow	101
509	240	240	176	93.24	-7.34	32.41	pale greenish yellow	104
510	240	240	208	93.71	-4.03	16.39	yellow white	92
511	240	240	240	94.29	0	0	white	263



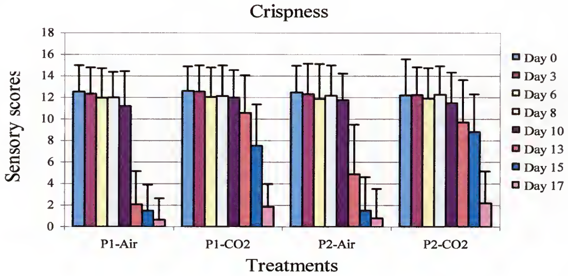


Figure 4-19. Average sensory scores of hardness and crispness as textural characteristics of zucchini slices stored under modified atmosphere over time for experiment II. Lines above bars denote standard errors.

selected to plot the color blocks (Table 4-13). From 30 color blocks for experiment I (Table 4-11) only 5 most important color blocks (444, 506, 509, 510, 511) for air treated (P1-Air) and 15%CO_2+ 2% O_2 (P1-CO_2) treated zucchini slices in first plastic bag and also 6 most important color blocks (444, 506, 509, 510, 511) for air treated (P2-Air) and (226, 444, 508, 509, 510, 511) 15%CO_2+ 2%O_2 (P2-CO_2) treated zucchini slices in second plastic bag, were selected to plot color blocks, because these selected colors were present in air and gas combinations treatments in higher levels of total area of the slices (Table 4-14). From 31 color blocks for experiment II (Table 4-12) only 9 and 6 most important color blocks, which were 369, 442, 444, 506, 507, 508, 509, 510, 511, for air (P1-Air) treated and , which were 444, 507, 508, 509, 510, 511, for 15%CO_2+ 2% O_2 (P1-CO_2) treated zucchini slices in first plastic bag, respectively, were selected to plot color blocks. Also, 13 and 7 most important color blocks, 297, 298, 369, 370, 442, 443, 444, 506, 507, 508, 509, 510, 511, for air (P2-Air) treated and which were 443, 444, 507, 508, 509, 510, 511, 15%CO_2+ 2% O_2 (P2-CO_2) treated zucchini slices in second plastic bag, respectively, were selected to plot color blocks (Table 4-15). It can be seen that CA experiment, experiment I and experiment II have different color profiles from each other except for color blocks of 508, 509, 510 that were seen in all experiments (Table 4-13 and Table 4-14). Moreover, experiment I and II had some similarities. The most important color for air treatment in CA experiment was 509 (RGB 240,240,176), which is responsible for the pale greenish yellow color. On average, 44% of the area of air treated zucchini slices in CA experiment was covered by this color, while in 7% and 15%CO_2 treated zucchini slices had 40% and 35%, respectively. Two other important colors were color block 510 (RGB 240, 240, 208, yellow white), and 508 (RGB 240, 240, 144, light

Table 4-12. Color blocks for experiment II.

Block #	R	G	B	L*	a*	b*	NBS Name	NBS #
152	80	112	16	38.39	-24.37	39.14	moderate olive green	125
153	80	112	48	38.52	-23.12	30.27	moderate olive green	125
154	80	112	80	38.88	-19.8	14.04	dark yellowish green	137
224	112	144	16	51.76	-25.67	49.48	strong yellow green	117
225	112	144	48	51.84	-24.9	43.22	strong yellow green	117
226	112	144	80	52.07	-22.82	30.06	moderate yellow green	120
227	112	144	112	52.5	-19.17	13.36	moderate yellowish green	136
233	112	176	48	62.42	-40.98	51.94	strong yellow green	117
296	144	176	16	64.66	-26.93	59.36	strong yellow green	117
297	144	176	48	64.72	-26.41	54.73	strong yellow green	117
298	144	176	80	64.88	-24.97	44.12	strong yellow green	117
299	144	176	112	65.18	-22.4	29.45	moderate yellow green	120
369	176	208	48	77.23	-27.8	65.35	brilliant yellow green	116
370	176	208	80	77.36	-26.74	56.72	brilliant yellow green	116
371	176	208	112	77.58	-24.84	43.99	brilliant yellow green	116
372	176	208	144	77.92	-21.98	28.81	light yellow green	119
433	208	208	48	80.2	-12.12	68.84	strong greenish yellow	99
434	208	208	80	80.32	-11.24	60.46	strong greenish yellow	99
441	208	240	48	89.43	-29.14	75.36	brilliant yellow green	116
442	208	240	80	89.53	-28.33	68.25	brilliant yellow green	116
443	208	240	112	89.71	-26.85	57.25	brilliant yellow green	116
444	208	240	144	89.98	-24.62	43.53	light yellow green	119
445	208	240	176	90.35	-21.59	28.21	light yellow green	119
446	208	240	208	90.84	-17.73	12.09	very light yellowish green	134
505	240	240	48	92.37	-13.77	78.78	brilliant greenish yellow	98
506	240	240	80	92.47	-13.08	71.86	brilliant greenish yellow	98
507	240	240	112	92.63	-11.83	61.09	brilliant greenish yellow	98
508	240	240	144	92.89	-9.93	47.57	light greenish yellow	101
509	240	240	176	93.24	-7.34	32.41	pale greenish yellow	104
510	240	240	208	93.71	-4.03	16.39	yellow white	92
511	240	240	240	94.29	0.00	0.00	white	263

Table 4-13. Most important color blocks for zucchini slices in controlled atmosphere experiment including air and both 7% and 15% CO_2 treatments, their L*a*b* values and their respective NBS color name..

Block #	R	G	B	L*	a*	b*	NBS Name	NBS #
152	80	112	16	38.39	-24.37	39.14	moderate olive green	125
224	112	144	16	51.76	-25.67	49.48	strong yellow green	117
425	208	176	80	71.51	6.80	52.7	strong yellow	84
433	208	208	48	80.2	-12.12	68.84	strong greenish yellow	99
441	208	240	48	89.43	-29.14	75.36	brilliant yellow green	116
496	240	208	48	83.71	3.76	72.9	brilliant yellow	83
505	240	240	48	92.37	-13.77	78.78	brilliant greenish yellow	98
506	240	240	80	92.47	-13.08	71.86	brilliant greenish yellow	98
507	240	240	112	92.63	-11.83	61.09	brilliant greenish yellow	98
508	240	240	144	92.89	-9.93	47.57	light greenish yellow	101
509	240	240	176	93.24	-7.34	32.41	pale greenish yellow	104
510	240	240	208	93.71	-4.03	16.39	yellow white	92

Table 4-14. Most important color blocks for zucchini slices in experiment I and II, their L*a*b* values and their respective NBS color name.

Experiment I

Block #	R	G	B	L*	a*	b*	NBS Name	NBS #
226	112	144	80	52.07	-22.82	30.06	moderate yellow green	120
444	208	240	144	89.98	-24.62	43.53	light yellow green	119
506	240	240	80	92.47	-13.08	71.86	brilliant greenish yellow	98
508	240	240	144	92.89	-9.93	47.57	light greenish yellow	101
509	240	240	176	93.24	-7.34	32.41	pale greenish yellow	104
510	240	240	208	93.71	-4.03	16.39	yellow white	92
511	240	240	240	94.29	0	0	white	263
Experiment II								
297	144	176	48	64.72	-26.41	54.73	strong yellow green	117
298	144	176	80	64.88	-24.97	44.12	strong yellow green	117
299	144	176	112	65.18	-22.4	29.45	moderate yellow green	120
369	176	208	48	77.23	-27.8	65.35	brilliant yellow green	116
370	176	208	80	77.36	-26.74	56.72	brilliant yellow green	116
442	208	240	80	89.53	-28.33	68.25	brilliant yellow green	116
443	208	240	112	89.71	-26.85	57.25	brilliant yellow green	116
444	208	240	144	89.98	-24.62	43.53	light yellow green	119
506	240	240	80	92.47	-13.08	71.86	brilliant greenish yellow	98
507	240	240	112	92.63	-11.83	61.09	brilliant greenish yellow	98
508	240	240	144	92.89	-9.93	47.57	light greenish yellow	101
509	240	240	176	93.24	-7.34	32.41	pale greenish yellow	104
510	240	240	208	93.71	-4.03	16.39	yellow white	92
511	240	240	240	94.29	0.00	0.00	white	263

greenish yellow). Color block 510 had average color values of 30% for air treatment, 38% for 7%CO_2 treatment, and 37% for 15%CO_2 treatment, while 508 was 8, 5, 7% in air and CO_2 treatments, respectively. The most important color for air treated and 15%CO_2 treated zucchini slices in first and second bag for experiment I and II was color 510. On average, for all treatments, color block 510 had color values of 60% and 55% for first and second experiment, respectively. The second important color for experiment I in all treatments was color 509. This color had average values of 12%. On the other hand, two other important colors for all treatments in experiment II were color block 511 (RGB 240, 240, 240), which is white, and color block 509. Color 511 had average values of 10%, 15%, 20%, 20% for air and CO_2 treated zucchini slices in first and second bags, respectively. Color 509 had average value of 10 %. This demonstrated that zucchini slice is a multicolor object, and therefore a single tristimulus value (XYZ or L*a*b*) will not be sufficient to quantify the colors present.

Color of zucchini slices changed with storage time. Figures 4-20, 4-21, 4-22 present the average values of the most important color blocks for each treatment in each experiment. Data for these figures are listed in Tables 4-15, 4-16 and 4-17, with their standard deviations. Color changed in different patterns, some increased during storage, others decreased. Some colors stayed constant, while others increased slowly and then decreased. The trends for different treatments in the controlled atmosphereexperiment were very similar. For air treatment in controlled atmosphereexperiment, color 509 (RGB, 240, 240, 176) first decreased from 34% to 27% from day 0 to day 4, then it increased up to 34% until day 6 then continuously decreased up to day 10, finally it stayed constant at 2% up to day 12. Color 510 (RGB, 240, 240, 208) first slightly increased then

Table 4-15. Color changes in controlled atmosphere experiment during storage at different treatments. Data averages (% of total view area of zucchini slices) of significant colors

Treatment	Storage time (days)	152		224		425		433		441		498	
		🟩		🟩		🟧		🟨		🟨		🟨	
		Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev
$15\%CO_2$	0	0.86	0.46	0.62	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.86	0.52	0.57	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	0.73	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	1.43	0.80	1.53	0.85	0.00	0.00	0.00	0.00	1.90	2.20	0.00	0.00
	12	0.77	0.86	0.55	0.57	0.00	0.00	0.00	0.00	1.92	2.45	0.00	0.00
$7\%CO_2$	0	0.93	0.52	0.45	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	1.21	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	0.52	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.60	0.52	0.44	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	0.84	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	2.25	1.51	2.00	1.55	0.00	0.00	0.94	1.88	2.78	2.46	0.00	0.00
	12	3.09	2.33	3.19	2.69	0.00	0.00	1.29	2.85	3.26	2.53	0.00	0.00
Air	0	0.81	0.60	0.58	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	1.94	0.69	1.33	0.35	0.00	0.00	0.82	0.42	0.00	0.00	0.00	0.00
	6	0.70	0.73	1.01	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	1.74	1.42	1.50	0.66	0.00	0.00	0.44	0.65	0.90	0.74	0.00	0.00
	10	4.43	2.18	4.63	2.76	1.18	2.52	8.65	3.00	1.52	1.89	0.92	1.77
	12	1.04	0.88	1.06	0.55	0.37	0.80	1.71	1.31	0.00	0.00	5.03	4.04

Treatment	Storage time (day)	505		506		507		508		509		510	
		🟨		🟨		🟨		🟨		🟨		🟨	
		Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St dev
$15\%CO_2$	0	0.00	0.00	0.23	0.60	1.88	2.47	7.97	6.13	25.64	11.63	42.89	19.80
	2	0.00	0.00	0.00	0.00	1.82	1.51	0.73	0.92	8.99	4.30	32.69	15.07
	4	0.00	0.00	0.00	0.00	0.68	0.74	5.07	3.52	24.64	6.56	50.64	6.16
	6	0.00	0.00	0.00	0.00	0.69	0.27	1.64	3.13	9.37	6.04	30.77	12.17
	8	0.00	0.00	0.00	0.00	3.03	3.86	16.16	12.30	35.04	13.28	26.76	22.89
	10	4.02	5.98	12.65	11.19	18.71	11.48	19.50	11.27	13.83	17.28	2.77	2.20
	12	2.82	5.79	12.62	13.53	17.66	10.25	18.66	10.49	11.88	10.19	8.39	13.07
$7\%CO_2$	0	0.00	0.00	0.00	0.00	0.62	0.69	7.57	2.99	32.17	15.64	41.08	19.08
	2	0.00	0.00	0.00	0.00	1.10	1.06	8.02	3.49	25.20	9.46	45.33	9.71
	4	0.00	0.00	0.00	0.00	0.74	0.64	8.32	4.79	31.03	11.56	41.79	14.22
	6	0.00	0.00	0.00	0.00	0.67	0.31	2.86	2.88	14.03	8.90	25.33	18.41
	8	0.13	0.37	1.03	1.34	7.22	5.16	24.46	14.63	36.06	13.33	11.35	8.84
	10	6.33	7.64	16.35	9.39	16.11	6.51	16.45	14.19	3.87	4.83	3.96	1.68
	12	5.91	6.69	18.72	10.81	13.53	8.62	8.50	9.50	5.07	8.10	1.82	0.83
Air	0	0.00	0.00	0.25	0.55	2.24	1.40	12.34	5.45	33.96	15.50	31.77	18.62
	2	0.00	0.00	0.00	0.00	0.93	1.04	8.13	4.88	33.51	11.93	41.41	13.46
	4	0.94	2.51	0.45	1.04	2.92	5.61	6.56	7.41	27.88	7.51	0.63	0.54
	6	0.00	0.00	0.57	0.31	5.36	5.26	26.56	15.85	33.97	10.03	1.22	1.71
	8	4.74	5.87	11.39	9.49	24.00	10.79	20.74	14.73	10.14	16.24	0.18	0.16
	10	6.73	6.30	6.07	6.10	1.20	1.66	0.95	1.55	1.12	0.80	1.17	0.99
	12	0.76	0.82	0.59	1.01	8.59	12.58	7.44	7.90	1.30	2.95	0.36	0.27

Table 4-16. Color changes in first experiment during storage at different treatments. Data averages (% of total view area of zucchini slices) of significant colors.

Treatments	Storage time (days)	226		444		508		509		510		511	
		🟩		🟩		🟨		🟨		🟨			
		Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev
P1-Air	0	1.83	0.98	2.73	0.83	2.25	2.29	16.48	5.92	54.53	9.00	0.82	1.16
	3	1.66	0.60	2.28	0.45	1.62	0.95	17.49	4.00	54.12	4.04	1.25	4.06
	6	1.65	0.43	2.29	0.51	1.48	1.62	12.98	2.01	55.26	9.55	5.22	9.59
	8	1.70	0.46	2.27	0.37	1.16	0.91	13.71	3.21	60.66	6.79	0.48	0.95
	10	1.88	0.82	2.33	0.26	1.75	1.51	14.20	3.65	57.15	6.54	1.74	2.90
	13	1.72	0.50	2.65	0.49	1.24	0.58	14.69	2.79	55.48	2.96	3.82	4.31
	15	1.82	0.78	2.59	0.61	1.33	0.85	13.80	2.68	57.06	7.19	0.94	1.67
	17	1.53	0.76	2.51	0.50	1.28	0.83	13.96	2.20	55.99	3.97	4.49	5.16
	22	1.47	0.66	2.22	0.33	3.00	1.34	18.13	6.94	52.78	7.08	2.58	5.15
	24	1.98	0.73	2.27	0.62	8.52	12.07	17.73	6.09	45.24	19.80	1.69	1.78
P1-CO$_2$	0	2.03	0.72	2.82	0.60	3.00	2.00	15.53	2.77	54.48	6.91	0.00	0.00
	3	2.04	0.80	2.71	0.30	1.45	0.42	15.22	2.21	54.48	3.67	2.25	2.45
	6	1.94	0.44	2.25	0.38	0.79	0.39	13.48	2.42	60.22	2.51	0.92	1.22
	8	1.96	0.80	2.43	0.72	0.93	0.80	12.58	3.00	58.42	6.02	1.71	2.62
	10	2.19	0.65	2.60	0.51	1.13	0.59	14.45	1.94	59.61	4.11	0.76	1.41
	13	1.94	0.42	2.41	0.57	0.78	0.58	11.22	3.80	59.47	4.46	4.32	5.24
	15	1.92	0.57	2.63	0.65	1.13	0.61	13.58	2.44	58.08	3.19	3.15	3.97
	17	1.67	0.79	2.45	0.44	1.35	0.67	14.27	3.51	54.27	6.06	6.97	8.45
	22	1.66	0.66	2.28	0.37	2.71	1.59	13.99	1.45	56.84	5.37	3.47	4.61
	24	1.83	0.91	2.20	0.19	2.69	1.46	15.21	2.71	48.11	5.49	8.16	6.45
P2-Air	0	1.51	0.71	2.55	0.46	2.05	0.97	15.50	2.68	59.04	5.15	0.25	0.55
	3	2.39	1.25	2.27	0.35	2.19	1.28	14.63	2.27	56.91	4.12	0.29	0.64
	6	3.94	1.17	2.80	0.42	1.38	0.78	13.94	2.65	52.41	4.27	3.13	1.71
	8	2.56	0.94	2.73	0.33	1.38	0.57	13.77	2.18	52.95	8.28	4.72	7.85
	10	1.87	0.67	2.57	0.48	0.98	0.47	13.87	3.33	55.82	6.88	4.30	5.59
	13	2.08	0.72	2.87	0.36	1.45	1.13	14.67	3.63	51.67	8.19	5.64	6.07
	15	2.29	0.93	2.30	0.46	0.81	0.52	11.11	1.95	58.25	3.28	3.92	3.93
	17	1.84	1.24	2.10	0.46	1.34	0.84	10.70	2.66	51.81	8.40	10.95	10.28
	22	2.00	1.16	2.34	0.62	6.29	8.20	19.99	6.27	43.50	16.04	3.76	6.61
	24	1.85	0.85	2.39	0.52	3.53	4.57	18.27	8.07	50.49	16.61	1.78	3.28
P2-CO$_2$	0	1.81	0.56	2.50	0.40	1.75	1.08	15.05	3.29	58.70	5.86	0.38	0.51
	3	1.78	0.72	2.43	0.41	1.15	1.01	16.89	6.01	58.60	7.27	0.70	1.34
	6	1.96	0.44	2.40	0.29	1.11	0.51	13.87	2.59	58.14	5.05	2.75	3.70
	8	2.10	0.57	2.73	0.38	1.13	0.61	13.08	1.74	57.10	3.80	2.71	2.36
	10	2.10	0.77	2.64	0.23	1.23	0.77	15.07	2.59	55.36	4.12	3.16	4.71
	13	1.94	0.61	2.46	0.42	1.58	0.75	14.85	2.45	58.16	4.92	2.12	4.15
	15	2.70	0.86	2.62	0.65	0.96	0.66	13.37	2.61	56.07	5.74	3.23	4.24
	17	1.27	0.79	2.44	0.38	1.52	0.66	13.22	2.58	55.36	7.11	7.76	8.45
	22	1.32	0.81	2.31	0.40	2.06	1.15	15.79	3.49	52.78	6.14	7.90	9.99
	24	1.88	0.80	2.11	0.32	4.44	4.26	24.81	8.38	44.55	13.32	0.73	1.05

Table 4-17. Color changes in second experiment during storage at different treatments. Data averages (% of total view area of zucchini slices) of most significant colors.

Treatments	Storage time (days)	297		298		369		370		442		443		444	
		🟩		🟩		🟩		🟩		🟩		🟩		🟩	
		Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev
P1-Air	0	0.00	0.00	1.10	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.30	2.03	0.43
	3	0.00	0.00	1.22	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.28	2.02	0.53
	6	0.00	0.00	1.11	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.11	0.44
	8	0.00	0.00	1.01	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.96	0.51
	10	0.00	0.00	1.26	0.65	0.00	0.00	0.64	0.30	0.00	0.00	0.90	0.56	2.63	0.75
	13	0.92	0.45	1.81	0.50	0.40	0.34	1.29	0.39	0.68	0.57	2.07	0.69	1.61	0.56
	15	1.37	0.46	1.31	0.28	0.92	0.50	1.42	0.39	1.44	0.67	2.02	0.72	0.97	0.38
	17	2.41	0.77	1.88	0.80	2.50	0.80	1.72	0.75	4.59	1.64	1.31	0.73	0.00	0.00
P1-CO$_2$	0	0.00	0.00	1.05	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.50	2.02	0.47
	3	0.00	0.00	1.27	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.38	2.37	0.44
	6	0.00	0.00	1.23	0.54	0.00	0.00	0.40	0.35	0.00	0.00	0.66	0.76	2.23	0.58
	8	0.00	0.00	1.41	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.39	2.01	0.33
	10	0.30	0.29	1.25	0.59	0.00	0.00	0.47	0.37	0.00	0.00	0.82	0.89	2.33	0.43
	13	0.00	0.00	1.59	0.77	0.00	0.00	0.81	0.44	0.00	0.00	1.19	0.83	2.41	0.40
	15	0.57	0.35	1.37	0.32	0.00	0.00	0.64	0.36	0.00	0.00	1.04	0.54	1.82	0.41
	17	1.47	0.27	1.46	0.28	0.76	0.50	1.36	0.19	1.96	1.79	2.15	0.34	1.48	0.53
P2-Air	0	0.00	0.00	1.24	0.35	0.00	0.00	0.56	0.31	0.00	0.00	0.82	0.67	2.25	0.50
	3	0.00	0.00	1.16	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.35	1.90	0.54
	6	0.00	0.00	1.14	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.24	0.56
	8	0.00	0.00	1.27	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.05	0.72
	10	0.41	0.38	1.50	0.70	0.00	0.00	0.54	0.42	0.00	0.00	0.64	0.62	2.46	0.39
	13	0.46	0.36	1.84	0.54	0.00	0.00	0.76	0.47	0.00	0.00	1.07	0.74	2.31	0.43
	15	0.91	0.57	1.56	0.58	0.60	0.69	1.40	0.43	1.36	1.39	2.05	0.71	1.72	0.61
	17	2.66	1.16	2.35	0.60	2.41	1.38	2.99	0.90	8.93	3.63	2.70	1.52	1.20	0.96
P2-CO$_2$	0	0.00	0.00	1.36	0.56	0.00	0.00	0.41	0.24	0.00	0.00	0.55	0.39	1.85	0.47
	3	0.00	0.00	1.46	0.48	0.00	0.00	0.42	0.26	0.00	0.00	0.58	0.35	2.33	0.64
	6	0.33	0.27	1.63	0.41	0.00	0.00	0.52	0.27	0.00	0.00	0.77	0.45	2.48	0.58
	8	0.00	0.00	1.49	0.53	0.00	0.00	0.40	0.32	0.00	0.00	0.57	0.42	2.14	0.39
	10	0.38	0.34	1.47	0.68	0.00	0.00	0.51	0.41	0.00	0.00	0.62	0.58	2.34	0.44
	13	0.00	0.00	1.83	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.35	2.58	0.61
	15	0.55	0.39	1.94	0.77	0.00	0.00	0.82	0.48	0.29	0.45	1.27	0.80	2.07	0.45
	17	1.07	0.41	1.82	0.45	0.31	0.39	1.33	0.54	1.10	1.22	2.63	2.06	1.86	0.70

Table 4-17. Continued

Treatments	Storage time (days)	506		507		508		509		510		511	
		Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev	Avg	St.dev
P1-Air	0	0.00	0.00	0.00	0.00	1.74	1.14	12.29	3.25	54.44	9.61	10.14	10.53
	3	0.00	0.00	0.00	0.00	1.33	0.67	11.96	3.31	52.16	10.69	14.50	13.25
	6	0.00	0.00	0.00	0.00	0.93	0.65	9.00	2.67	40.69	13.55	30.68	14.88
	8	0.00	0.00	0.00	0.00	1.18	0.62	11.23	5.98	57.59	10.98	11.29	14.39
	10	0.00	0.00	0.00	0.00	2.35	2.25	15.20	10.02	45.68	11.92	16.38	12.34
	13	0.24	0.50	3.04	2.72	16.11	10.95	28.94	7.03	27.12	16.91	0.00	0.00
	15	1.35	1.76	9.61	9.14	22.87	9.43	29.76	14.13	11.44	9.02	0.00	0.00
	17	13.9	8.41	21.50	8.28	12.06	8.89	3.09	3.38	5.03	3.28	1.19	0.60
P1-CO_2	0	0.00	0.00	0.00	0.00	1.58	0.70	11.12	2.16	48.85	14.89	16.17	15.59
	3	0.00	0.00	0.00	0.00	1.62	0.97	11.27	4.28	43.23	12.23	20.59	16.24
	6	0.00	0.00	0.00	0.00	1.29	1.14	9.30	1.98	39.46	14.64	27.74	14.48
	8	0.00	0.00	0.00	0.00	1.35	1.08	9.64	1.53	48.54	13.17	18.14	13.55
	10	0.00	0.00	0.00	0.00	1.55	1.55	10.28	1.24	44.62	13.30	21.44	11.11
	13	0.00	0.00	0.00	0.00	2.22	1.61	11.57	1.29	52.55	10.73	11.34	8.53
	15	0.00	0.00	1.02	1.90	8.01	8.82	21.66	12.48	46.36	20.19	2.34	3.13
	17	1.55	2.12	7.82	5.28	21.28	11.42	26.06	8.62	14.35	12.09	0.28	0.37
P2-Air	0	0.00	0.00	0.00	0.00	1.50	0.81	12.07	2.68	43.23	12.56	21.42	14.16
	3	0.00	0.00	0.00	0.00	0.87	0.60	7.96	2.71	38.16	14.05	34.33	15.25
	6	0.00	0.00	0.00	0.00	0.75	0.37	8.89	2.34	37.01	13.10	30.77	15.07
	8	0.00	0.00	0.00	0.00	0.87	0.49	9.27	3.35	47.68	14.61	22.47	17.46
	10	0.00	0.00	0.00	0.00	1.23	1.12	10.21	2.15	43.13	13.60	23.62	15.04
	13	0.00	0.00	0.93	1.50	6.61	9.35	21.45	13.51	42.79	20.47	6.71	8.08
	15	4.16	6.56	11.93	9.96	23.60	11.33	21.47	14.20	13.97	14.69	0.92	0.52
	17	14.0	7.82	19.80	9.34	10.16	8.63	2.76	2.13	4.95	2.63	2.11	1.43
P2-CO_2	0	0.00	0.00	0.00	0.00	1.15	0.58	8.96	2.08	44.30	9.40	23.59	10.89
	3	0.00	0.00	0.00	0.00	0.90	0.54	9.67	1.93	34.23	12.67	33.34	14.78
	6	0.00	0.00	0.00	0.00	1.39	0.64	10.61	1.36	40.04	12.15	25.71	11.68
	8	0.00	0.00	0.00	0.00	1.19	0.89	10.20	2.62	49.16	11.82	18.43	11.02
	10	0.00	0.00	0.00	0.00	1.22	1.08	9.86	2.20	44.99	13.20	21.99	14.83
	13	0.00	0.00	0.00	0.00	1.02	0.46	13.39	4.33	55.63	7.51	6.17	6.94
	15	0.57	1.41	2.27	3.86	5.96	6.17	19.27	8.53	46.43	17.81	2.05	2.91
	17	1.58	4.34	6.84	7.44	19.64	11.54	27.30	10.98	15.71	13.15	1.33	0.42

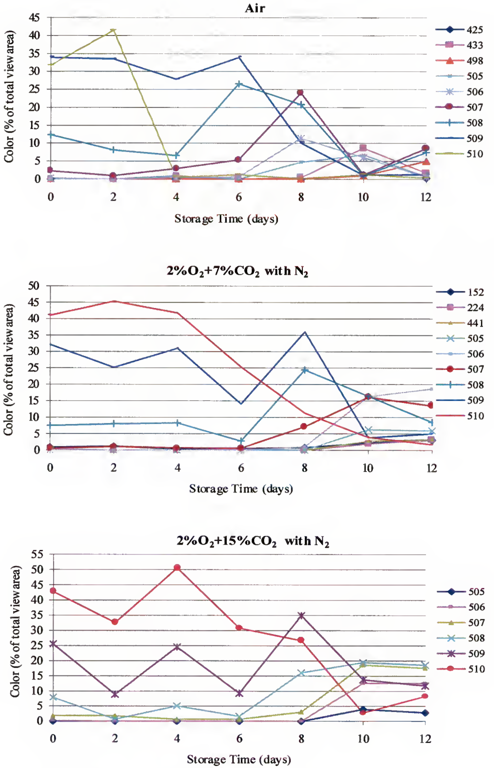


Figure 4-20. Color changes of zucchini slices over time in controlled atmosphere experiment at different atmospheres, points represent the average of 8 slices.

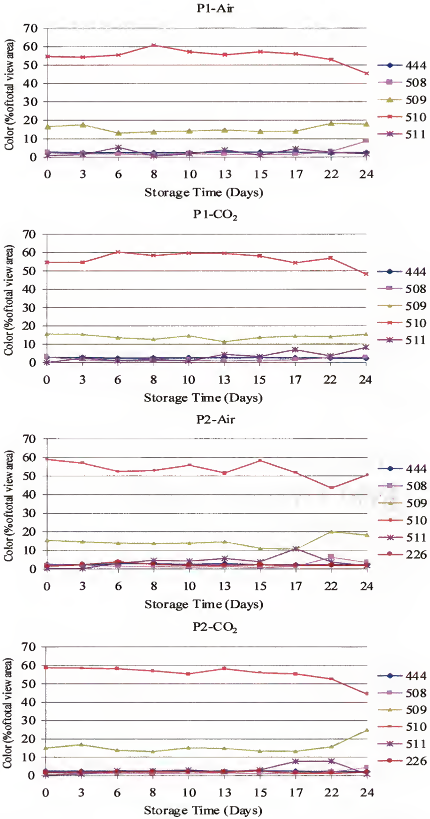


Figure 4-21. Color changes of zucchini slices over time in experiment I at different atmospheres, points represent the average of 12 slices.

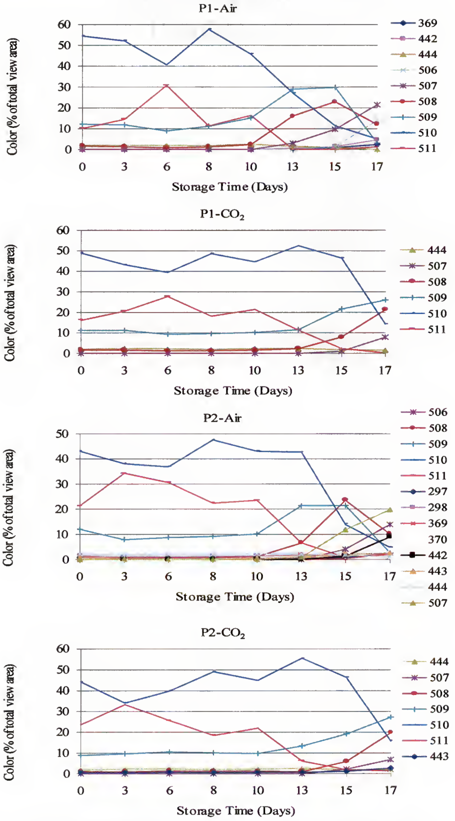


Figure 4-22. Color changes of zucchini slices over time in experiment II at different atmospheres, points represent the average of 12 slices.

decreased immediately to 2% and stayed constant up to day 12. Color 508 (RGB, 240, 240, 144) first slightly decreased and increased up to 26% at day 6, then decreased again until day 10, after that it showed slight increase to 7% up to day 12. Color 507 (RGB, 240, 240, 208) increased up to day 8 (25%) then decreased until day 10 to 2% and finally it showed slight increase up to day 12 (8%). For CO_2 treatments (7% and 15%) in CA experiment, color 509, 506, 507 and 508 showed similar trends. Color 509 had stepwise decrease, while 506, 507, 508 started to form after days 6 and 8. Color 510 had different decreasing trend in both CO_2 treatments. 7%CO_2 treatment had smooth decrease up to 12 days, however 15% CO_2 treatment showed stepwise decrease (Figure 4-20 and Table 4-15). For experiment I, color 510 in air and CO_2 treated samples in first bags showed a decline from 60% to 45% from day 0 to 24. Color 509 showed similar trend in both treatments. Color 511 increased after day 10 up to day 24 to 10% . In second bag, color 510 slightly decreased up to day 22 then slightly increased until day 24. Color 509 decreased until day 17 then increased up to day 20 then stayed constant, while color 511 showed slight increase until day 17, then it decreased. For CO_2 treated slices in second bag, color 510 decreased, while color 509 decreased up to day 17 then increased slightly. Color 511 first increased from 0% to 8% up to day 17, then it stayed constant until day 22. Finally, it showed a sharp decrease to 0% (Figure 4-21 and Table 4-16). For experiment II, air and CO_2 treatments in first and second bags had similar trends. Colors 510 and 511 decreased during storage while 444, 506, 507and 509 increased (Figure 4-22 and Table 4-17).

In general, flesh color changed from white (color 511) or yellow white (color 510) color to strong greenish yellow color (colors, 433, 434) because of discoloration and natural deterioration by day 10 to 12 for CA experiment. Similar observations were reported by Izumi and Watada (1995) in zucchini slices treated with $CaCl_2$ and stored in polyethylene bags with 0.5% CO_2. According to their results, at 5°C the cut surface became discolored (brown) by days 13 and 9. However, the surface of the color of zucchini was not a good index of quality (Mencarelli et al., 1983). Color remained virtually unchanged regardless of storage temperature or O_2 concentration. This behavior is in sharp contrast with cucumbers (Apeland, 1961; Eaks and Morris, 1957). In some cases, because the flesh of zucchini slices was separated from peel due to decay, it affected the last color, which was moderate olive green in color analysis evaluation.

For experiment I, with all treatments, color changed very slightly from white or yellow white to light yellow green (color 444, RGB, 208, 240,144) by day 22 to 24. Color changed very slowly especially in CO_2 treated samples in first bag. Generally, color changes during experiment I were less pronounced than CA or experiment II. This was observed visually and by color data analysis. Throughout storage, zucchini slices remained with the original colors in slices treated with CO_2. Similar result was observed from whole zucchini squash stored under higher CO_2 and 5°C. All different sizes of fruit stored in 10%CO_2 were free of injury and pitting on the surface (Mencarelli, 1987).

For experiment II, with air treated samples in first and second bags, color changed from white and yellow white to strong yellow green, which was color 298 (RGB, 144, 176, 80) by day 13. For CO_2 treated zucchini slices in first and second bags, color also changed from white and yellow white to light yellow green, which was color 444 (RGB, 208, 240, 144) by day 15. Generally, white color changed to light greenish yellow, which was color 508 (240, 240, 144) up to 17 days.

L*a*b* values from the Color Analysis software were obtained during storage. Figure 4-23, 4-24, 4-25 and Table 4-18, 4-19, 4-20 show the average trends for these parameters. For CA experiment, air treated zucchini slices showed slight decrease in L* until day 10. Lightness dropped from 90% to 65% by day 10 and 12, respectively. With the 7% CO_2 treatment, lightness had no change up to day 10. It decreased from 90% to 80% at day 12. There was no change in 15% CO_2 treated zucchini slices during storage. For experiment I, L* did not change with air and CO_2 treated zucchini slices during storage. For experiment II, L* in air treated slices packaged with first and second bags first increased very slightly up to day 13 then decreased by day 17. With treated CO_2 slices in first and second bags, L* first slightly increased then dropped to its initial value, which was 90%. The a* value showed first a decrease then steep increase up to day 8 then sharp decrease at day 12. 7%CO_2 treatment in controlled atmospherehad a steep increase from 17% to 20% by day 12, while 15%CO_2 presented first a decrease and then steep increase up to day 12. For experiment I, air treated samples in first bag had a 1% decrease after day 6 and then remained constant, while air treated slices in second bag showed very slight increases and decreases by day 24. Change in a* value was 1% during storage. CO_2 treated slices in first and second bags had similar trends up to day 10. After day 10, samples in first bags stayed constant, however, samples in the second bags had very slight decrease and increase. For experiment II, with all treatments, a* value showed an increase. Air treated slices with both bags had higher increase than CO_2 treated slices. A higher a* values denotes a change into the green colors.

For CA experiment, air treated slices had an increase in b* value up to day 8 then they showed a steep decrease by day 12. 7%CO_2 treated slices had a steep increase by day

Table 4-18. Average L*, a* and b* values for zucchini slices used in controlled atmosphere experiment (n=21)

Treatments	Storage time (days)	L*		a*		b*	
		Avg	St.dev	Avg	St. dev.	Avg	St. dev.
Air	0	91.25	5.73	-15.50	3.01	36.53	4.21
	2	92.96^{a}	5.27	-10.16^{a}	2.01	33.48	3.53
	4	88.84^{a}	7.17	-13.76	2.34	46.54^{a}	4.28
	6	91.39	5.83	-14.76	2.23	54.27^{a}	4.22
	8	87.24^{a}	7.39	-16.28	2.48	64.36^{a}	6.07
	10	69.45^{a}	7.98	-16.14	2.71	55.01	7.05
	12	68.77^{a}	8.57	-5.99^{a}	3.87	52.93	7.07
7%CO_2	0	91.61	5.64	-14.43	2.94	33.41	3.56
	2	90.90^{ab}	6.00	-14.61^{b}	2.86	33.38	4.09
	4	91.88^{b}	5.53	-14.72	2.82	33.34^{b}	3.70
	6	90.54	6.51	-14.36	2.73	37.87^{b}	3.90
	8	91.09^{ab}	5.98	-15.06	2.86	43.43^{b}	4.29
	10	85.24^{b}	5.59	-18.12	1.97	57.05	5.00
	12	81.14^{b}	7.65	-19.68^{b}	2.43	57.59	6.37
15%CO_2	0	90.99	5.84	-15.15	3.04	33.14	4.39
	2	88.85^{b}	7.11	-15.09^{b}	2.89	34.29	3.93
	4	92.13^{b}	5.51	-13.87	2.87	30.86^{b}	3.92
	6	91.43	5.77	-15.41	2.97	34.07^{b}	4.10
	8	91.88^{b}	5.40	-15.09	2.94	38.37^{b}	3.84
	10	89.56^{b}	4.80	-17.53	2.21	56.67	4.12
	12	90.16	4.99	-18.39^{b}	2.78	53.89	4.84

*:Avg: Average of 30 readings from both replications

*:St. dev. : Standard deviation of 30 readings from both replications

^{a,b}: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

Table-4-19 Average L*, a* and b* values for modified atmosphere stored zucchini slices used in first experiment (n=40)

Treatments	Storage time (days)	L*		a*		b*	
		Avg	St. dev.	Avg	St. dev.	Avg	St. dev.
P1-Air	0	91.53	3.89	-14.20^{b}	2.51	28.88	2.94
	3	91.32^{ab}	4.00	-14.00	2.59	29.13	2.83
	6	91.51^{a}	3.93	-13.75^{a}	2.58	26.49	3.05
	8	91.35	4.18	-13.36	2.43	27.02	2.68
	10	91.40	4.03	-13.37	2.48	27.79	2.86
	13	91.74	3.88	-13.47^{bc}	2.47	27.03^{ab}	2.87
	15	90.00	4.66	-12.88	2.41	27.26	2.90
	17	91.95	3.78	-13.49^{a}	2.53	26.50	3.04
	22	91.87	3.90	-13.31^{a}	2.43	28.80^{ab}	3.11
	24	91.22	4.20	-13.61	2.49	31.85	3.38
P1-CO_2	0	91.18	3.98	-14.24^{b}	2.56	29.92	3.08
	3	90.74^{b}	4.28	-14.12	2.63	27.90	3.02
	6	91.51^{a}	4.07	-13.56^{a}	2.55	26.63	2.74
	8	90.57	4.40	-14.17	2.47	26.53	2.77
	10	91.74	3.95	-12.90	2.38	27.64	2.76
	13	91.88	3.95	-13.11^{c}	2.47	25.55^{b}	2.72
	15	91.70	4.01	-12.98	2.45	26.52	2.83
	17	92.37	3.69	-13.05^{ab}	2.53	26.05	3.05
	22	92.01	3.93	-12.79^{ab}	2.53	27.33^{b}	3.23
	24	90.89	4.23	-13.85	2.59	27.73	3.47
P2-Air	0	92.31	3.64	-13.50^{ab}	2.40	29.00	2.78
	3	90.61^{b}	4.33	-13.98	2.57	28.82	3.05
	6	88.62^{b}	5.22	-11.12^{b}	1.98	27.28	2.78
	8	90.57	4.31	-13.56	2.56	27.36^{a}	3.06
	10	91.59	3.99	-13.35^{ab}	2.51	26.53	2.86
	13	91.13	4.07	-13.93	2.56	27.36	3.11
	15	90.75	4.36	-13.17	2.47	25.74	2.85
	17	91.58	3.86	-13.42^{a}	2.46	25.09	3.24
	22	91.36	4.02	-13.21^{ab}	2.30	31.49^{a}	3.29
	24	91.32	4.03	-13.37	2.52	29.93	3.04
P2-CO_2	0	91.73	3.94	-13.31^{a}	2.44	28.53	2.90
	3	92.38^{a}	3.68	-13.45^{c}	2.41	27.82	2.60
	6	91.36^{a}	4.19	-12.67	2.39	26.84	2.84
	8	91.19	4.14	-13.63	2.51	26.70	2.91
	10	91.29	4.14	-13.08	2.40	27.28	2.84
	13	92.00	3.94	-12.57^{a}	2.42	27.56^{a}	2.91
	15	90.98	4.21	-13.31	2.47	27.10	2.69
	17	92.55	3.60	-12.64^{b}	2.29	26.36	3.02
	22	92.72	3.59	-12.44^{b}	2.27	27.32^{b}	3.04
	24	91.34	4.11	-13.22	2.42	31.62	3.05

*:Avg: Average of 30 readings from both replications.

*:St. dev. : Standard deviation of 30 readings from both replications.

$^{a\text{-}c}$: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.

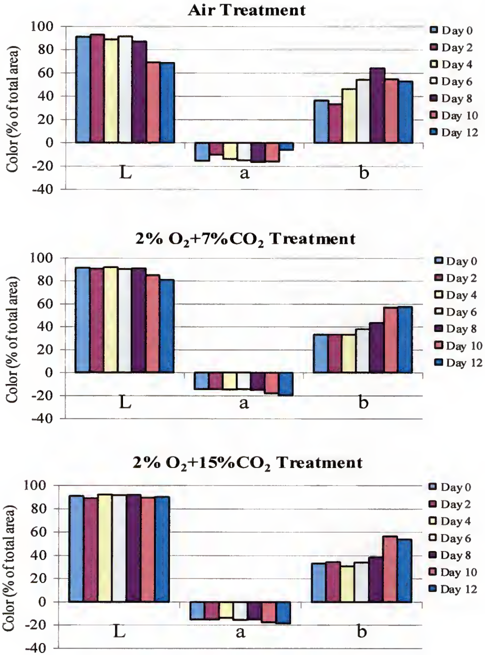
Table 4-20. Average L*, a* and b* values for modified atmosphere stored zucchini slices used in second experiment (n=40)

Treatments	Storage time (days)	L*		a*		b*	
		Avg	St. dev.	Avg	St. dev.	Avg	St. dev.
P1-Air	0	91.91	4.16	-12.98	2.41	25.53^{a}	3.05
	3	92.63^{a}	3.91	-12.21^{ab}	2.36	24.25^{a}	3.09
	6	94.26^{a}	2.86	-11.65^{a}	2.28	21.87	3.14
	8	94.04^{a}	2.98	-12.17^{a}	2.28	24.28	2.88
	10	93.90	2.95	-12.59	2.35	26.05^{a}	3.32
	13	92.19	3.59	-14.30^{a}	2.38	38.27^{a}	3.63
	15	91.95	3.77	-14.94^{a}	2.32	45.14^{a}	3.81
	17	87.31^{a}	4.26	-19.88^{a}	2.20	55.72^{a}	5.03
P1-CO_2	0	91.69	4.24	-12.77	2.46	24.86^{a}	3.36
	3	91.35^{b}	4.39	-12.86^{b}	2.55	24.37^{a}	3.38
	6	93.00^{ab}	3.41	-12.81^{b}	2.55	22.65	3.50
	8	92.56^{b}	3.66	-12.87^{b}	2.49	23.48	3.31
	10	93.04	3.41	-12.81	2.52	24.07^{ab}	3.43
	13	93.05	3.32	-12.92^{b}	2.47	25.88^{b}	3.47
	15	93.14	3.42	-13.04^{b}	2.37	31.41^{b}	3.21
	17	91.05^{b}	3.89	-16.35^{b}	2.58	43.88^{b}	3.94
P2-Air	0	92.24	3.99	-12.47	2.47	24.68^{a}	3.40
	3	93.28^{a}	3.63	-11.55^{a}	2.19	21.23^{b}	3.19
	6	92.74^{b}	3.53	-12.59^{b}	2.45	22.06	3.25
	8	93.84^{a}	3.09	-11.89^{a}	2.36	22.42	3.06
	10	93.27	3.27	-12.26	2.40	23.52^{b}	3.31
	13	93.21	3.27	-12.53^{b}	2.12	29.71^{b}	3.12
	15	92.86	3.11	-15.68^{a}	2.12	45.82^{a}	4.00
	17	87.46^{a}	3.80	-20.89^{a}	2.00	54.35^{a}	5.09
P2-CO_2	0	91.83	4.21	-12.18	2.39	22.61^{b}	3.27
	3	92.46^{a}	3.77	-12.95^{b}	2.47	22.05^{b}	3.57
	6	93.33^{ab}	3.15	-12.97^{b}	2.55	23.34	3.57
	8	93.43^{ab}	3.21	-12.17^{a}	2.40	23.19	3.18
	10	93.18	3.26	-12.77	2.39	23.51^{b}	3.27
	13	92.17	3.81	-12.15^{b}	2.22	26.23^{b}	2.86
	15	92.39	3.60	-12.95^{b}	2.24	31.07^{b}	3.48
	17	91.60^{b}	3.63	-15.38^{b}	2.34	41.74^{b}	3.74

*:Avg: Average of 30 readings from both replications

*:St. dev. : Standard deviation of 30 readings from both replications

a-c: Superscripts within each treatment denote significant difference at the $p<0.05$. Means were separated using LSD.



Air Treatment

2% O_2+7%CO_2 Treatment

2% O_2+15%CO_2 Treatment

Figure 4-23. Average L*a*b* values of zucchini slices used in controlled atmosphere experiment, measured by the color machine vision system n=21.

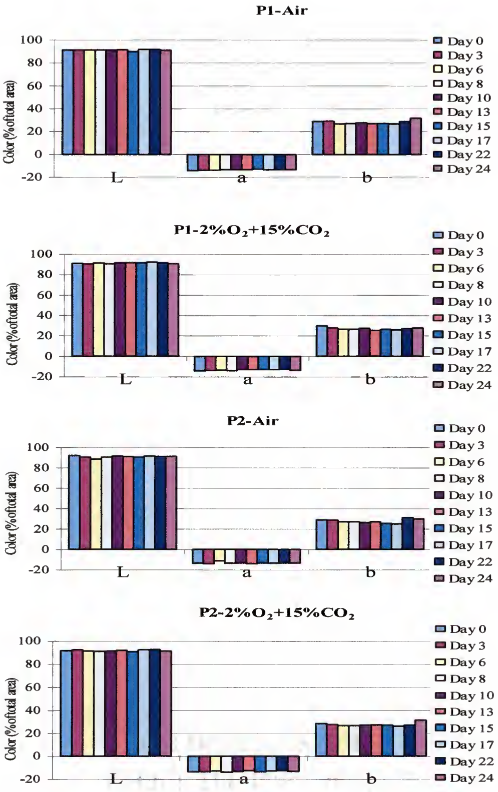
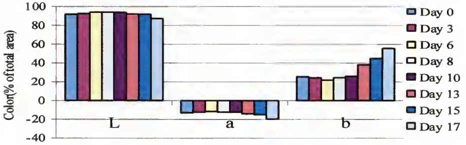
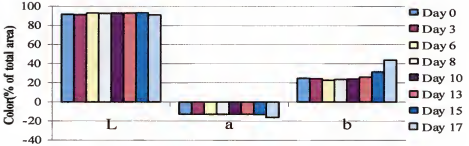


Figure 4-24. Average L*a*b* values of modified atmosphere stored zucchini slices used in experiment I, measured by the color machine vision system n=40.

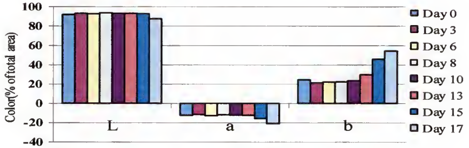
P1-Air



P1-2%O_2+15%CO_2



P2-Air



P2-2% O_2+15%CO_2

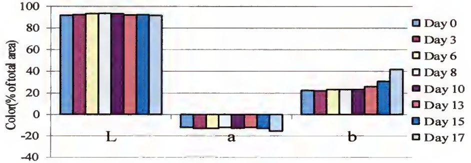


Figure 4-25. Average L*a*b* values of modified atmosphere stored zucchini slices used in experiment II, measured by the color machine vision system n=40.

12. Also, 15%CO_2 treated samples had an increase in b* value up to 10 days, then slightly decreased. For experiment I, b* value first decreased about 1% then leveled off in air treated zucchini slices packed in first bag. For the air treated samples in second bag there was a slight decrease in b* value up to day 22 and then it showed an increase at day 22 but it decreased on day 24. For CO_2 treated slices, b* values changed similarly : a slight decrease at first, then a slight increase in both bags. Theoretically, b* values express yellowness or blueness which is positive for yellow and negative for blue. In this study, an increase in the b* value means a change into yellow. As seen from the data, visual observation throughout the experiments can be correlated well with the data obtained from the color analysis. Statistical differences ($p< 0.05$) between treatments was also determined using analysis of variance (SAS Institute Inc. 2001, Cary, NC). For controlled atmospherestudy, there was a significant treatment, storage time and treatment x storage time interaction effect ($p<0.05$). 15%CO_2+2% O_2 treatment resulted in less decline in L* compared with storage under 7%CO_2+2% O_2 and air treatments ($p<0.05$). There was a significant difference in a* value between both 7% and 15% CO_2 treatments and air treatment although there was not significant difference between 7% and 15% CO_2 treatments. Highest increase in a* value was with 7%CO_2 while lowest increase was with air treatment. A significant main effect for treatments together with storage time and their interactions was observed in a* value ($p<0.05$). There was also significant main and interaction effects on b* value ($p<0.05$). Highest increase in b* value was observed with air samples, however lowest change was observed in 15% CO_2 samples. Similarly, there was not a significant difference between CO_2 treatments. For first experiment, although treatment x time interaction was not statistically significant ($p<0.05$), a

significant main effect for treatment and day on L* was observed. Even though there was not much difference between CO_2 and air treatments in first and second bags, highest decline in L* value was with air treated samples with second bag. Significant main effects for treatment and storage time and their interaction on a* and b* value was observed ($p<0.05$). Highest increase on a* value was with air treated zucchini slices in first bag. Lowest increase on b* value was with CO_2 treated zucchini slices in first bag. For second experiment, a significant treatment x time interaction and day effect on L* value was seen although there was not significant effect for treatments ($p<0.05$). There was no decline of L value for all treatments, which means no browning during storage. Highest increase of a* and b* values was with air treated samples in first bag ($p<0.05$). Both a* and b* values also had significant effect for treatments, day and their interactions ($p<0.05$). Similar study was performed by Berrang et al. (1990). They studied L*a*b* changes of three different vegetables during the controlled atmosphere storage using different gas combinations. Vegetables were asparagus, broccoli and cauliflower. They reported that color attributes of asparagus indicate that controlled atmosphere storage (CAS) had only a slight effect during storage. The L* and a* value did not differ significantly with respect to atmosphere composition throughout storage. On day 21, a* value of asparagus stored under air was lower than that under CAS. Color changes in broccoli were not significantly affected by the storage atmosphere. These results were confirmed by the visual observation that all broccoli maintained a similar color when stored under air and CAS during storage. Storage of cauliflower under CA resulted in change of color. CAS caused lower decline in L* value compared with storage under air. Subjective inspection showed the florets stored under air become brown earlier during storage compared to florets under CAS. A significant increase in chroma for both treatments was noted during storage. However, storage atmosphere did not have significant effect on b* value. There was also no significant difference in a* value change during storage, regardless of atmosphere (Berrang et al., 1990). Izumi and Watada (1995) also measured the color expressed as the L* and hue angle (tan-1 b*/a*) values. They reported that color did not change with slices held at 5°C. However it decreased after day 6 only in control slices at 10°C, and the decrease in L* and hue angle values coincided with the onset browning and decay. These results indicated that color deterioration was characterized mainly by browning.

Overall, L*a*b* values did not change with storage time for experiment I. There was a slight change in L* value with but moderate change in a*b* value for P1-Air and P2-Air treatments. However, P1-CO_2 and P2-CO_2 treatments prevented L* change over time although they caused still a very slight change in a*b* values. Generally it was lower for CO_2 treatments than for air treatments. As a result, the surface color of zucchini was not a good index of quality. Color remained unchanged regardless of gas concentration and package type. This behavior was similar to another zucchini study (Mencarelli et al., 1987) but sharp contrast to cucumbers, which yellow readily as they age (Apeland, 1961; Eaks and Morris, 1957). In CA experiment, air and 7% CO_2 treatment resulted in a higher change in L*a*b values than 15% CO_2 treatment over time. This led to browning of slices. Results from sensory study also confirmed that CO_2 treatment suppressed color change. Similar effect was also observed during experiment II.

Color blocks used for DFA analysis for CA experiment, experiment I and experiment II were shown in Tables 4-10, 4-11, and 4-12. Tables 4-21, 4-22 and Figures 4-26, 4-27 and 4-28 represent the DFA results when color data and storage time were used as grouping variables for CA experiment, experiment I and experiment II, respectively. Color block data from all experiments were reduced to two discriminant functions. The classification of color data for each analysis time was very good in all treatments. The overall correct classification rates for air, 7%CO_2 +2%O_2 and 15%CO_2 +2%O_2 treated zucchini slices for controlled atmosphere experiment were all 100%. The overall correct classification rates for P1-Air, P1-CO_2, P2-Air and P2-CO_2 were 95.83%, 97.50%, 94.17% and 97.50%, respectively, for experiment I and 87.50%, 95.83%, 93.75% and 92.71%, respectively, for experiment II. These results shows that the color machine vision data was able to detect differences in color at each analysis day for all experiments. Cross validation results using DFA are shown in Tables 4-21, 4-22. The overall correct cross validation classification rates for air, 7%CO_2 +2%O_2 and 15%CO_2 +2%O_2 treated zucchini slices for controlled atmosphere experiment were 100%. The overall cross validation classification rates for P1-Air, P1-CO_2, P2-Air and P2-CO_2 were 96.36%, 97.27%, 94.55% and 95.45%, respectively, for experiment I and 87.50%, 96.59%, 95.45% and 94.32%, respectively, for experiment II. These results show that there was a good prediction using cross validation method in different treated samples, after training. When the treatments, color data and storage times were pooled together, correct classification rates were 97.62% for CA experiment, 78.13% for first experiment and 72.39% for experiment II. These results showed that analyzing pooled data in DFA resulted in more dispersion with lower classification rates. DFA for each treatment (air,

Table 4-21. Correct classification and cross validation rates obtained from classification matrix for DFA of color data when treatments and storage times were used as grouping variables for controlled atmosphere experiment.

Storage Time (days)	Controlled Atmosphere Experiment					
	Correct Classification Rates (%)			Cross Validation Rates (%)		
	Treatments			Treatments		
	air (n=56)	$2\%O_2+7\%CO_2+N_2$ (n=56)	$2\%O_2+15\%CO_2+N_2$ (n=56)	air (n=56)	$2\%O_2+7\%CO_2+N_2$ (n=56)	$2\%O_2+15\%CO_2+N_2$ (n=56)
0	100.00	100.00	100.00	100.00	100.00	100.00
2	100.00	100.00	100.00	100.00	100.00	100.00
4	100.00	100.00	100.00	100.00	100.00	100.00
6	100.00	100.00	100.00	100.00	100.00	100.00
8	100.00	100.00	100.00	100.00	100.00	100.00
10	100.00	100.00	100.00	100.00	100.00	100.00
12	100.00	100.00	100.00	100.00	100.00	100.00
Overall	100.00	100.00	100.00	100.00	100.00	100.00

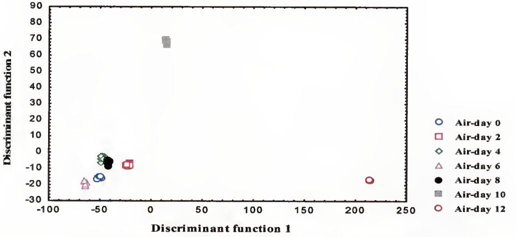
n=number of slices used for color data readings to obtain DFA functions

Table 4-22. Correct classification and cross validation rates for DFA of color data of first and second experiment

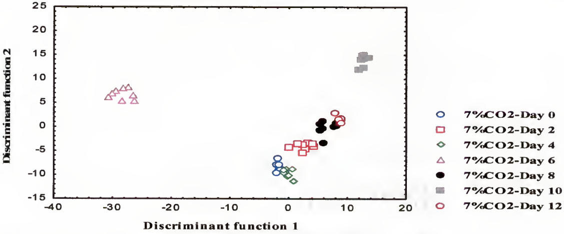
Storage Time (days)	Correct Classification Rates (%)							
	Treatments							
	Experiment I				Experiment II			
	P1-Air (n=120)	P1-CO_2 (n=120)	P2-Air (n=120)	P2-CO_2 (n=120)	P1-Air (n=96)	P1-CO_2 (n=96)	P2-Air (n=96)	P2-CO_2 (n=96)
0	100.00	91.67	100.00	91.67	75.00	91.67	91.67	91.67
3	100.00	100.00	83.33	100.00	83.33	91.67	100.00	100.00
6	100.00	100.00	100.00	91.67	75.00	91.67	100.00	83.33
8	100.00	91.67	100.00	100.00	83.33	100.00	100.00	91.67
10	100.00	100.00	100.00	100.00	91.67	100.00	91.67	91.67
13	83.33	100.00	100.00	91.67	100.00	100.00	75.00	100.00
15	100.00	100.00	100.00	100.00	91.67	91.67	91.67	83.33
17	83.33	100.00	91.67	100.00	100.00	100.00	100.00	100.00
22	100.00	91.67	91.67	100.00	-	-	-	-
24	91.67	100.00	75.00	100.00	-	-	-	-
Overall	95.83	97.50	94.17	97.50	87.50	95.83	93.75	92.71

Storage Time (days)	Cross Validation Rates (%)							
	Treatments							
	Experiment I				Experiment II			
	P1-Air (n=120)	P1-CO_2 (n=120)	P2-Air (n=120)	P2-CO_2 (n=120)	P1-Air (n=96)	P1-CO_2 (n=96)	P2-Air (n=96)	P2-CO_2 (n=96)
0	100.00	90.91	100.00	90.91	72.73	90.91	90.91	100.00
3	100.00	100.00	81.82	90.91	72.73	90.91	100.00	100.00
6	100.00	100.00	100.00	90.91	81.82	90.91	100.00	81.82
8	100.00	90.91	100.00	100.00	81.82	100.00	100.00	90.91
10	100.00	100.00	100.00	100.00	90.91	100.00	100.00	100.00
13	90.91	100.00	100.00	81.82	100.00	100.00	81.82	100.00
15	100.00	100.00	100.00	100.00	100.00	100.00	90.91	81.82
17	81.82	100.00	90.91	100.00	100.00	100.00	100.00	100.00
22	100.00	90.91	90.91	100.00	-	-	-	-
24	90.91	100.00	81.82	100.00	-	-	-	-
Overall	96.36	97.27	94.55	95.45	87.50	96.59	95.45	94.32

Air treatment in controlled atmosphere experiment
(100% Correct classification)



7% CO_2+2% O_2 treatment in controlled atmosphere experiment
(100 % Correct classification)



15% CO_2+2% O_2 treatment in controlled atmosphere experiment
(100 % Correct classification)

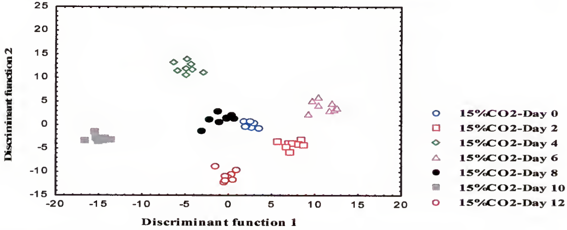
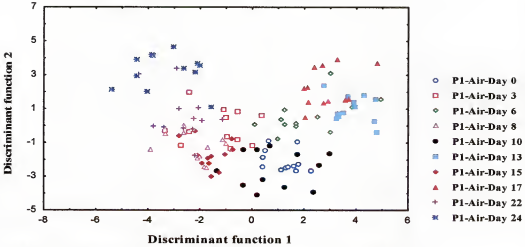


Figure 4-26. DFA results of color data and storage time of zucchini slices treated with air, 7%CO2+2%O2 and 15%CO2+ 2% O2.

Air treatment in first plastic bag for experiment I
(95.83% Correct classification)



15% CO_2+2% O_2 treatment in first plastic bag for experiment I
(97.50% Correct classification)

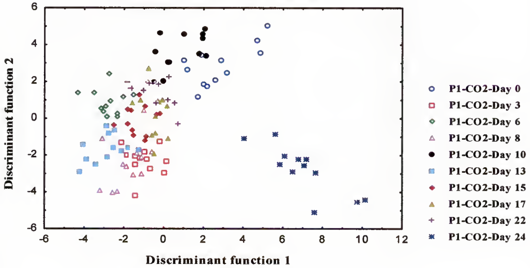
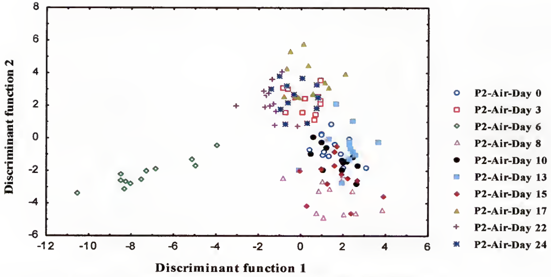


Figure 4-27. DFA results of color data and storage time of zucchini slices packaged in two different plastic bags and two different gas combinations (air and 15%CO_2+ 2% O_2 balance with N_2).


Air treatment in second plastic bag for experiment I
(94.17% Correct classification)

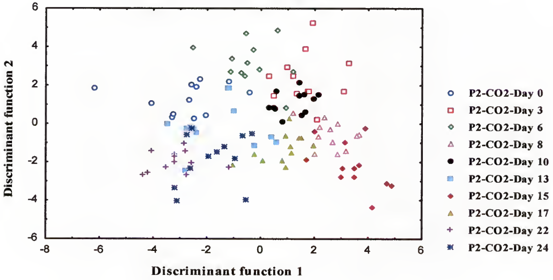
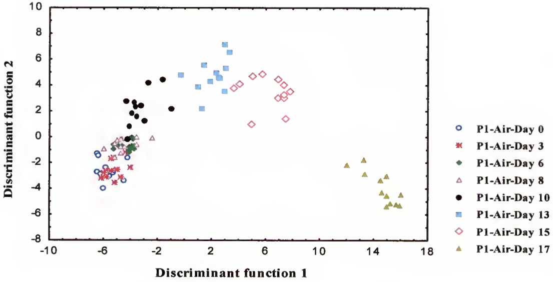

2% O_2+15% CO_2 treatment in second plastic bag for experiment I
(97.50% Correct classification)

Figure 4-27. Continued.

Air treatment in first plastic bag for experiment II
(87.50 % Correct classification)



15%CO_2+2%O_2 in first plastic bag for experiment II
(95.83 % Correct classification)

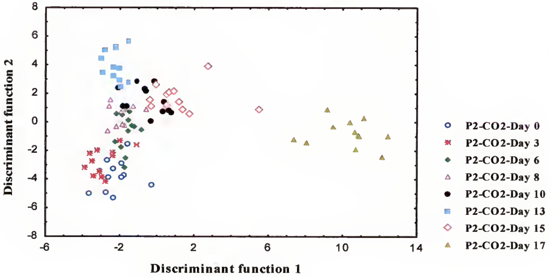
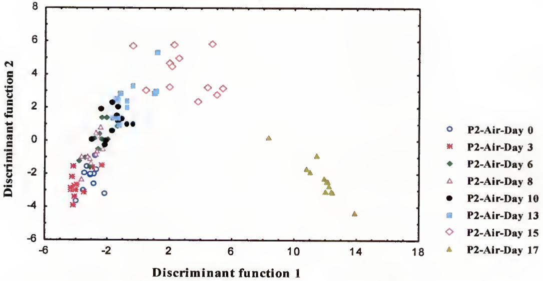


Figure 4-28. DFA results of color data and storage time of zucchini slices packaged in two different plastic bags and two different gas combinations (air and 15%CO_2+ 2% O_2 balance with N_2)


Air treatment in second plastic bag for experiment II (93.75 % Correct classification)

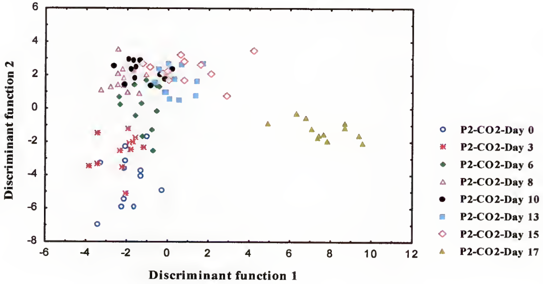

15% CO_2+2% O_2 treatment in second plastic bag for experiment II (92.70 % Correct classification)

Figure 4-28.Continued

$7\%CO_2 + 2\%O_2$ and $15\%CO_2 + 2\%O_2$), at each analysis day for controlled atmosphere experiment showed high classification rates when color data were classified by treatments. Treatments at each time (day 0, 2,4,6,8,10,12) were also classified 100%, for CA experiment (Table 4-23). Treatments (P1-Air, P1-CO_2, P2-Air and P2-CO_2) were highly classified for each analysis day (0, 3, 6, 8, 10, 13, 15, 17, 22, 24) for experiment I and II (Tables 4-24 and 4-25). The classification rates of treatments at each sampling day for experiment I were 98%, 100%, 100%, 98%, 100%, 100%, 100%, 100%, 98% and 98% from day 0 to 24, respectively. Those for experiment II were100%, 96%, 98%, 96%, 88%, 94%, 98% and 100% from day 0 to 17, respectively.

Electronic Nose Measurements:

Electronic nose data showed good classification results based on treatments and storage time for CA experiment, experiment I and experiment II. Electronic nose data was analyzed separately for each experiment. The electronic nose discriminated the odor changes in zucchini slices stored in two different modified atmosphere conditions using two different plastic bags as packages for all experiment (Tables 4-26 and 4-27). The overall correct classification rates of air, $7\%CO_2 + 2\%O_2$ and $15\%CO_2 + 2\%O_2$ treated zucchini slices for CA experiment during storage were 100%, 100% and 97.14%, respectively (Figure 4-29). The overall correct classification rates for P1-Air, P1-CO_2, P2-Air and P2-CO_2 were 98.33%, 100.00%, 93.33% and 100.00%, respectively, for experiment I (Figure 4-30 and Table 4-27) and 100.00%, 95.83%, 97.92% and 100.00%, respectively, for experiment II (Figure 4-31 and Table 4-27) . These results show that the electronic nose detected differences in sample odors for all experiments.

Table 4-23. Correct classification rates obtained from the DFA of color data grouped by the treatments. DFA models were obtained for each measurement time

Treatments	Controlled Atmosphere Experiment						
	Correct Classification Rates (%)						
	Storage Time (days)						
	0	2	4	6	8	10	12
air (n=56)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2%O_2+7%CO_2+N_2 (n=56)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2%O_2+15%CO_2+N_2 (n=56)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Overall	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-24. Correct classification rates obtained from the DFA of color data grouped by the treatments. DFA models were obtained for each measurement time.

Treatments	Experiment I									
	Correct Classification Rates (%)									
	Storage Time (days)									
	0	3	6	8	10	13	15	17	22	24
P1-Air (n=120)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
P1-CO_2 (n=120)	91.67	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
P2-Air (n=120)	100.00	100.00	100.00	91.67	100.00	100.00	100.00	100.00	91.67	91.67
P2-CO_2 (n=120)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Overall	97.92	100.00	100.00	97.92	100.00	100.00	100.00	100.00	97.92	97.92

Table 4-25. Correct classification rates obtained from the DFA of color data grouped by the treatments. DFA models were obtained for each measurement time.

Treatments	Experiment II							
	Correct Classification Rates (%)							
	Storage Time (days)							
	0	3	6	8	10	13	15	17
P1-Air (n=96)	100.00	100.00	100.00	91.67	100.00	91.67	100.00	100.00
P1-CO_2 (n=96)	100.00	91.67	91.67	100.00	100.00	91.67	91.67	100.00
P2-Air (n=96)	100.00	100.00	100.00	91.67	83.33	91.67	100.00	100.00
P2-CO_2 (n=96)	100.00	91.67	100.00	100.00	66.67	100.00	100.00	100.00
Overall	100.00	95.83	97.92	95.83	87.50	93.75	97.92	100.00

Table 4-26. Correct classification and cross validation rates obtained from classification matrix for DFA of e-nose data when treatments and storage times were used as grouping variables for controlled atmosphere experiment.

Storage Time (days)	Controlled Atmosphere Experiment					
	Correct Classification Rates (%)			Cross Validation Rates (%)		
	Treatments			Treatments		
	air (n=35)	2%O_2+7%CO_2 +N_2(n=35)	2%O_2+15%CO_2 +N_2 (n=35)	air (n=35)	2%O_2+7%CO_2 +N_2(n=35)	2%O_2+15%CO_2 +N_2(n=35)
0	100.00	100.00	100.00	100.00	100.00	100.00
2	100.00	100.00	100.00	100.00	100.00	100.00
4	100.00	100.00	100.00	100.00	100.00	100.00
6	100.00	100.00	100.00	100.00	100.00	100.00
8	100.00	100.00	80.00	100.00	100.00	100.00
10	100.00	100.00	100.00	100.00	100.00	100.00
12	100.00	100.00	100.00	100.00	100.00	100.00
Overall	100.00	100.00	97.14	100.00	100.00	100.00

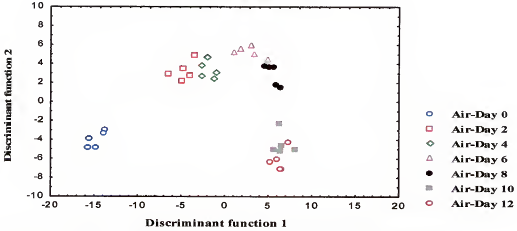
n=number of slices used for color data readings to obtain DFA functions

Table 4-27. Correct classification and cross validation rates for DFA of e-nose data of first and second experiment

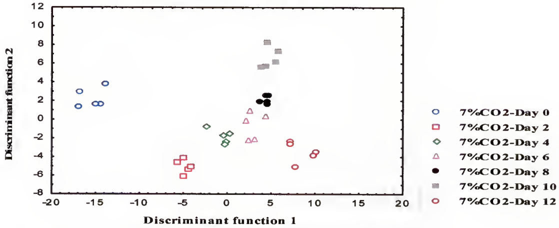
Storage Time (days)	Correct Classification Rates (%)							
	Treatments							
	Experiment I				Experiment II			
	P1-Air (n=60)	P1-CO_2 (n=60)	P2-Air (n=60)	P2-CO_2 (n=60)	P1-Air (n=48)	P1-CO_2 (n=48)	P2-Air (n=48)	P2-CO_2 (n=48)
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
3	100.00	100.00	100.00	100.00	100.00	83.33	83.33	100.00
6	100.00	100.00	83.33	100.00	100.00	83.33	100.00	100.00
8	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
13	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
15	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
17	83.33	100.00	100.00	100.00	100.00	100.00	100.00	100.00
22	100.00	100.00	66.67	100.00	-	-	-	-
24	100.00	100.00	83.33	100.00	-	-	-	-
Overall	98.33	100.00	93.33	100.00	100.00	95.83	97.92	100.00

Storage Time (days)	Cross Validation Rates (%)							
	Treatments							
	Experiment I				Experiment II			
	P1-Air (n=60)	P1-CO_2 (n=60)	P2-Air (n=60)	P2-CO_2 (n=60)	P1-Air (n=48)	P1-CO_2 (n=48)	P2-Air (n=48)	P2-CO_2 (n=48)
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
3	100.00	100.00	100.00	100.00	100.00	100.00	80.00	100.00
6	100.00	100.00	100.00	100.00	100.00	80.00	100.00	100.00
8	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
13	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
15	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
17	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
22	100.00	100.00	100.00	100.00	-	-	-	-
24	100.00	100.00	80.00	100.00	-	-	-	-
Overall	100.00	100.00	98.00	100.00	100.00	97.50	97.50	100.00

Air treatment for controlled atmosphere experiment
(100 % Correct classification)



$7\% CO_2+2\% O_2$ treatment for controlled atmosphere experiment
(100 % Correct classification)



$15\%CO_2+2\%O_2$treatment for controlled atmosphere experiment
(97.14% Correct classification)

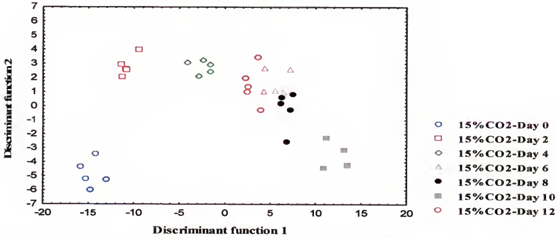
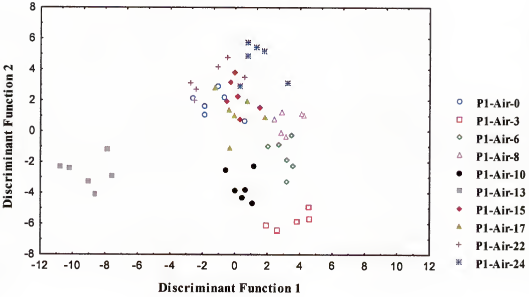
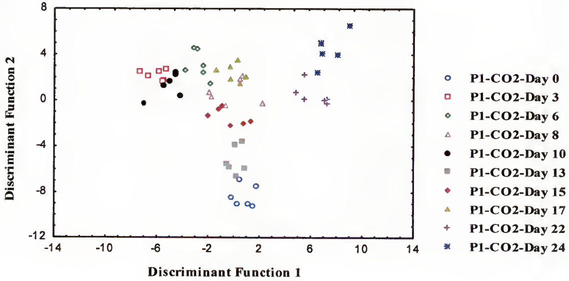


Figure 4-29. DFA of electronic nose analysis of controlled atmosphere experiment.



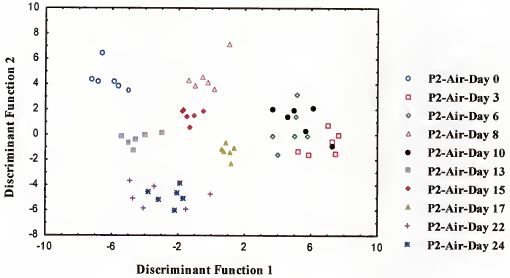
Air treatment in first bag for experiment I
(98.33% Correct classification)



15%CO_2+2%O_2 treatment in first bag for experiment I
(100% Correct classification)

Figure 4-30. DFA results of electronic nose readings and storage time of zucchini slices stored in 2 different modified atmosphere conditions using 2 different plastic bags for experiment I.

Air treatment in second bag for experiment I
(93.33% Correct classification)



$15\%CO_2+2\%O_2$ treatment in second bag for experiment I
(100% Correct classification)

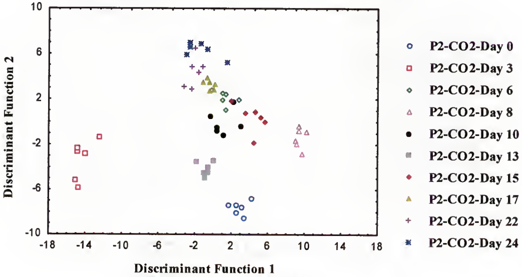
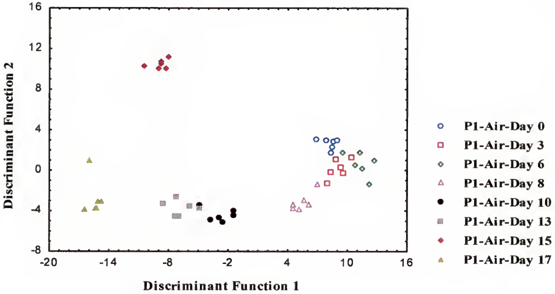


Figure 4-30. Continued

Air treatment in first bag for experiment II
(100% Correct classification)



15%CO2+2%O2 treatment in first bag for experiment II
(95 % Correct classification)

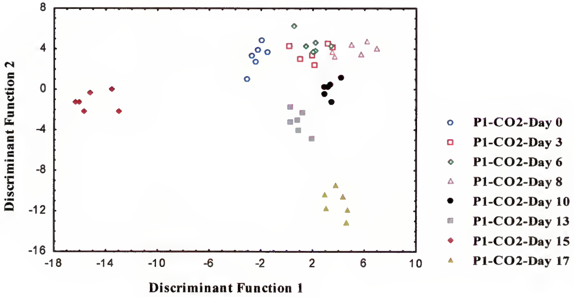
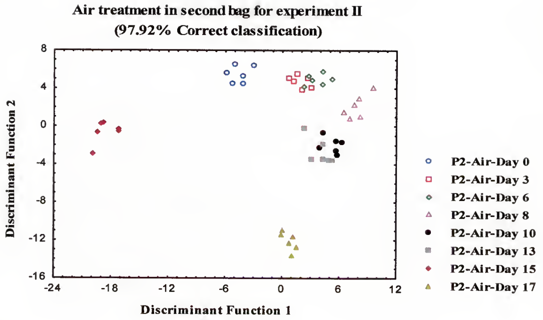


Figure 4-31. DFA results of electronic nose readings and storage time of zucchini slices stored in 2 different modified atmosphere conditions using 2 different plastic bags for experiment II.



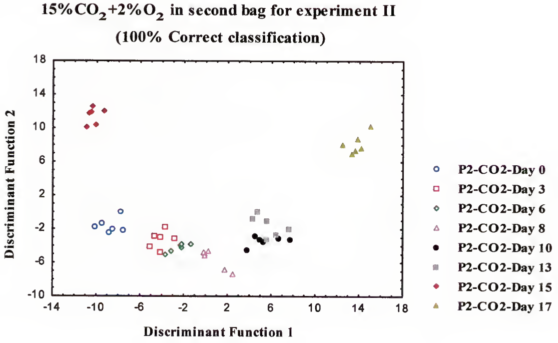


Figure 4-31. Continued.

Cross validation results using DFA are shown in Tables 4-26 and 4-27. The overall correct cross validation classification rates based on sensor readings for air, 7%CO_2 +2%O_2 and 15%CO_2 +2%O_2 treated zucchini slices for CA experiment were 100%, 100% and 100%, respectively. Those for P1-Air, P1-CO_2, P2-Air and P2-CO_2 were 100%, 100%, 98% and 100%, respectively, for experiment I and 100%, 97.50%, 97.50% and 100% for experiment II.

Data from all treatments of each experiment at each sampling day were pooled together to observe better discrimination between the treatments over time. Electronic nose sensor readings and storage times of all treatments were used as grouping variables. DFA was applied to the twelve sensor outputs from all treatments, and these 12 sensor readings were reduced to two functions (Table 4-28). These two functions (all treatments $_{\text{func 1 and 2}}$) were used to calculate coordinates of points for data at each storage time. For example, for air, 7%CO_2 +2%O_2 and 15%CO_2 +2%O_2, 12 sensor readings from CA experiment were taken and these values were multiplied with specific coefficients of discriminant function 1 and 2 and summed with constant. The correct classification rates on pooled data were 92.38% for CA experiment, 83.33% for experiment I and 84.37% for experiment II. Based on the results of treatments from each experiment, it was decided that electronic nose sensor data should be analyzed separately for every analysis time (0, 2, 4, 6, 8, 10, 12 for CA experiment; 0, 3, 6, 8, 10, 13, 15, 17, 22, 24 for experiment 1 and 0, 3, 6, 8, 10, 13, 15 and 17 for experiment II). As expected from storage studies, properties of zucchini slices were changing during storage. Some of these changes could influence the odor of zucchini slices, which in fact was demonstrated by the DFA on electronic sensor data. In all experiments, the classification of sensor data for each

Table 4-28. DFA coefficients for treatments and storage times correlated to electronic nose sensor readings for controlled atmosphere experiment, experiment I and experiment II with all data pooled together.

Experiments	Coefficients (T_n* = electronic nose sensor type)											
(Function)	T_{301}	T_{298}	T_{297}	T_{283}	T_{278}	T_{264}	T_{263}	T_{262}	T_{261}	T_{260}	T_{259}	T_{258}
Preliminary $_{\text{func 1}}$	-1.87	5.96	3.08	-9.67	0.77	8.38	3.68	-0.92	-6.58	-2.00	0.89	-0.93
Preliminary $_{\text{func 2}}$	1.45	0.86	-2.25	-1.34	1.28	7.54	-2.87	-2.91	-1.45	0.53	-2.79	2.69
Experiment I $_{\text{func 1}}$	-1.79	-0.12	14.58	-4.80	-10.13	-5.31	22.02	-8.14	-8.69	10.05	-1.96	-5.65
Experiment I $_{\text{func 2}}$	3.53	-0.80	3.82	-0.02	-1.05	3.47	-4.53	0.70	-3.55	-2.04	5.59	-4.91
Experiment II $_{\text{func 1}}$	2.70	2.70	-4.04	1.24	2.47	-1.34	-4.63	1.74	4.10	2.07	-2.06	-4.97
Experiment II $_{\text{func 2}}$	-2.18	0.41	1.73	1.04	-3.56	-4.37	14.22	-9.95	0.35	3.13	1.68	-2.63

*Sensor type= T_{301}

analysis time was good. The overall classification rates of air, 7%CO_2 +2%O_2 and 15%CO_2 +2%O_2 treated zucchini slices for CA experiment was 100% at days 0, 2, 4, 6, 8, 10,and 12 (Table 4-29). The overall classification rates of P1-Air, P1-CO_2, P2-Air and P2-CO_2 treatments for experiment I ranged from 100% to 95.83% at each analysis day (Table 4-30). Classification rates of same treatments for experiment II were also 95.83%, 100%, 100%, 100%, 100%, 100%, 100%, and 95.83% at days 0, 3, 6, 8, 10, 13, 15 and 17 (Table 4-31). These results shows that electronic nose was able to sense differences in odor at each analysis day.

Principal Component Analysis (PCA) and Canonical Discrimination Analysis (CDA) for Controlled Atmosphere Experiment

PCA Color Data of Controlled Atmosphere Experiment

Table 4-32 presents the means and variances for the %colors of different modified atmosphere stored samples. Table 4-33 shows the eigenvalues of the correlation matrix and their proportion of explained variance. It can be seen that the cumulative variance reached 82% at the thirteenth eigenvalue, so if we use 13 principle components, which are 13 colors out of 47, that would be enough to describe the data for further correlation analysis.

Performance of the PCA tells us how much reduction is possible and the directions of most variability. Since the first principal component explains maximum variation (measured in terms of total variance), the first principal component can be used for choosing color data. Table 4-33 shows that largest eigenvalue is 11.00 so that the first principal component explains about 23% of total variability. The second principal component with a variance of 7.17 (15% of the total variation) measures a difference

Table 4-29. Correct classification rates obtained from the DFA of electronic nose sensor readings grouped by the treatments. DFA models were obtained for each sampling time

Treatments	Controlled Atmosphere Experiment						
	Correct Classification Rates (%)						
	Storage Time (days)						
	0	2	4	6	8	10	12
air (n=35)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
$2\%O_2+7\%CO_2+N_2$ (n=35)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
$2\%O_2+15\%CO_2+N_2$(n=35)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Overall	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-30. Correct classification rates obtained from the DFA of electronic nose sensor readings grouped by the treatments. DFA models were obtained for each sampling time

Treatments	Experiment I									
	Correct Classification Rates (%)									
	Storage Time (days)									
	0	3	6	8	10	13	15	17	22	24
P1-Air (n=60)	100.00	83.33	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
P1-CO_2 (n=60)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
P2-Air (n=60)	100.00	100.00	100.00	100.00	100.00	83.33	100.00	100.00	83.33	83.33
P2-CO_2 (n=60)	100.00	100.00	100.00	100.00	83.33	100.00	100.00	100.00	100.00	100.00
Overall	100.00	95.83	100.00	100.00	95.83	95.83	100.00	100.00	95.83	95.83

Table 4-31. Correct classification rates obtained from the DFA of electronic nose sensor readings grouped by the treatments. DFA models were obtained for each sampling time

Treatments	Experiment II							
	Correct Classification Rates (%)							
	Storage Time (days)							
	0	3	6	8	10	13	15	17
P1-Air (n=48)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
P1-CO_2(n=48)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	83.33
P2-Air(n=48)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
P2-CO_2(n=48)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Overall	95.83	100.00	100.00	100.00	100.00	100.00	100.00	95.83

Table 4-32. Mean and standard deviation of colors used for PCA analysis for controlled atmosphere experiment.

Color	Mean (%)[1]	Std Dev [1]	Minimum	Maximum
C8	0.42	1.16	0	7.05
C16	0.14	0.45	0	4.76
C80	0.83	1.22	0	7.52
C81	0.15	0.50	0	3.05
C88	0.50	0.61	0	3.98
C152	1.16	1.38	0	7.73
C153	0.59	0.60	0	3.13
C160	0.42	0.62	0	3.59
C216	0.12	0.39	0	2.44
C224	0.93	1.48	0	8.58
C225	0.60	0.62	0	3.09
C226	0.29	0.53	0	2.92
C232	0.17	0.42	0	3.10
C233	0.21	0.41	0	2.00
C288	0.15	0.56	0	3.99
C296	0.56	1.58	0	13.19
C297	0.57	0.88	0	4.08
C298	0.45	0.53	0	2.29
C305	0.12	0.34	0	2.24
C360	0.38	1.63	0	15.52
C361	0.19	1.00	0	9.71
C368	0.27	0.85	0	5.29
C369	0.49	1.19	0	8.34
C370	0.54	0.85	0	6.56
C378	0.15	0.35	0	2.26
C426	0.39	2.11	0	16.3
C432	0.23	0.86	0	5.61
C433	0.64	2.02	0	13.51
C434	0.17	0.66	0	5.04
C435	0.23	1.27	0	10.19
C440	0.14	0.87	0	9.58
C441	0.58	1.49	0	7.20
C442	0.64	1.04	0	8.84
C443	0.87	0.57	0	2.75
C444	0.94	0.65	0	3.37
C445	0.49	0.49	0	2.29
C490	0.21	1.43	0	12.76
C497	0.24	1.16	0	11.57
C498	0.26	1.33	0	10.11
C499	0.44	2.26	0	17.37
C505	1.54	4.02	0	21.07
C506	3.65	7.94	0	45.34
C507	5.94	8.79	0	37.53
C508	11.15	11.54	0	55.97
C509	20.16	15.73	0	60.85
C510	21.11	21.46	0	64.25
C511	0.32	1.12	0	11.52

[1] 8 replications used for mean and st. dev. calculations for color measurements for PCA

Table 4-33. Eigenvalues and percent total variability of the correlation matrix obtained by PCA for color data set of controlled atmosphere experiment.

Principal components	Eigenvalue	Difference	Proportion	Cumulative
1	11.00	3.82	0.23	0.23
2	7.17	3.15	0.15	0.38
3	4.01	1.06	0.08	0.47
4	2.95	0.55	0.06	0.53
5	2.40	0.21	0.05	0.58
6	2.19	0.46	0.04	0.63
7	1.72	0.11	0.03	0.66
8	1.61	0.25	0.03	0.70
9	1.36	0.13	0.02	0.73
10	1.22	0.13	0.02	0.75
11	1.09	0.09	0.02	0.78
12	1.01	0.07	0.02	0.80
13	0.92	0.10	0.01	0.82

between color blocks. All the remaining principal components account for variation of less than 9%. It is difficult to give any clear-cut interpretation to these components. The richness of color in zucchini samples of this experiment, and the results of PCA suggest that the 13 colors highlighted in column1 in Table 4-34 provide good discriminator for quality analysis. Also, these selected 13 colors can provide better correlation with sensory evaluations

CDA of Color Data of Controlled Atmosphere Experiment

It is observed from the cumulative column that the first three canonical variable can explain more than 90% of total variance. Associated F statistics are also significant Related tables of these results are shown in Appendix D. Results suggests that 3 canonical variables would do a satisfactory job of describing the color data.

The raw coefficients of canonical variables (Can1 and Can2) are shown in Table 4-35. The first canonical variable appears to represent a contrast between two groups of color. It means that disappearance of light colors, formation of medium and dark colors can be separated using CDA when samples started to decay. First canonical variable was mostly affected by c216, c368, c369, c426, c435, c498, which are medium and dark colors representing formation of decay on the product. The second canonical variable appears to be largely influenced by c216, c288, c360, c435, c 499, c497, c361 , c490, c432.

Attempting to use color discrimination among treatments by time groups we observe about 3 color functions to be able to separate these groups. Each color function is typically very effective in separating one or two time treatment *time combinations from all others (Table 4-36). For example, Can1 is very effective in separating Air

Table 4-34. Eigenvectors (PCA coefficients) from color data set of zucchini controlled atmosphere experiment.

Color	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10	Prin11	Prin12	Prin13	Prin14
C8	0.15	-0.05	-0.10	0.04	-0.25	0.19	0.03	0.19	-0.20	0.02	0.20	0.27	0.10	0.10
C16	0.01	0.06	-0.05	0.12	0.18	0.17	-0.12	0.25	-0.34	0.18	-0.24	0.09	0.35	-0.25
C80	**0.19**	0.11	-0.13	0.04	0.04	0.26	-0.09	-0.01	-0.09	-0.07	-0.03	0.08	0.00	0.07
C81	0.09	-0.26	0.03	0.16	-0.02	0.14	0.03	0.11	0.02	0.04	0.34	0.03	-0.07	0.13
C88	0.04	0.16	-0.10	0.23	0.24	0.23	0.02	-0.07	-0.10	0.20	-0.19	-0.06	0.09	0.10
C152	**0.22**	0.14	-0.11	0.10	0.02	0.11	-0.17	-0.10	0.02	-0.06	-0.03	0.04	-0.03	0.00
C153	0.10	-0.07	-0.07	0.02	0.20	0.19	-0.06	0.38	0.03	0.04	0.12	-0.35	0.05	0.28
C160	0.04	0.17	-0.05	0.26	0.22	0.12	0.15	-0.24	-0.02	0.19	-0.03	0.00	-0.16	0.17
C216	**0.21**	-0.21	0.02	-0.05	0.10	-0.03	0.00	-0.08	0.06	0.10	-0.12	-0.14	0.02	0.04
C224	**0.24**	0.14	-0.06	0.10	0.04	0.03	-0.11	-0.12	0.05	-0.15	-0.04	-0.05	-0.03	-0.04
C225	0.16	0.06	0.10	-0.19	0.23	0.02	-0.08	0.23	0.18	0.15	0.09	0.01	-0.21	0.00
C226	0.15	-0.22	0.07	0.06	0.15	-0.11	-0.12	0.06	0.11	-0.05	0.05	0.00	-0.03	0.15
C232	0.06	0.17	0.07	0.26	0.17	0.02	0.12	-0.22	0.00	0.28	0.16	0.09	-0.27	-0.06
C233	0.00	0.12	0.24	-0.08	0.10	0.27	0.19	0.16	0.25	0.01	-0.07	0.10	-0.12	-0.25
C288	**0.22**	-0.05	-0.22	-0.14	-0.15	0.17	0.04	-0.01	0.10	0.12	0.11	-0.02	-0.01	-0.07
C296	**0.22**	0.16	-0.10	0.05	0.00	0.00	-0.05	-0.10	0.10	-0.16	0.06	-0.20	0.05	-0.21
C297	**0.23**	0.09	0.13	-0.18	-0.01	-0.08	0.01	-0.01	-0.09	-0.15	-0.11	0.07	-0.08	0.08
C298	0.07	-0.09	0.13	-0.13	0.35	-0.07	-0.19	0.19	0.16	0.12	0.15	0.01	0.04	-0.03
C305	0.00	0.10	0.29	-0.09	-0.07	0.20	0.30	0.07	0.27	0.06	-0.05	-0.10	0.02	-0.24
C360	**0.20**	-0.07	-0.21	-0.04	-0.17	0.23	0.04	-0.05	0.13	-0.04	0.16	-0.07	0.04	-0.20
C361	0.17	-0.04	-0.11	-0.34	0.10	-0.07	0.09	-0.12	-0.06	0.27	-0.11	0.12	0.04	-0.05
C368	0.17	0.18	-0.03	0.24	0.03	-0.18	-0.02	0.01	0.25	0.05	0.09	0.01	0.17	-0.14
C369	**0.22**	0.16	0.06	-0.13	0.13	-0.05	0.05	0.00	-0.14	-0.24	0.06	0.06	-0.04	0.02
C370	0.15	-0.21	0.24	-0.01	0.14	-0.06	-0.11	-0.05	-0.01	-0.13	-0.04	0.08	0.03	0.07
C378	-0.04	0.06	0.18	-0.11	-0.06	0.22	0.43	-0.03	0.18	-0.09	-0.10	-0.12	0.31	0.23
C426	0.10	-0.24	0.01	0.18	-0.15	0.21	0.11	0.06	-0.04	0.00	0.27	0.21	-0.04	-0.04
C432	**0.18**	0.09	-0.15	-0.02	-0.13	-0.08	-0.11	0.01	0.20	-0.13	-0.19	-0.15	0.14	0.13
C433	**0.24**	-0.03	-0.17	-0.20	-0.03	0.02	0.00	-0.09	0.05	-0.09	-0.10	-0.03	0.04	-0.07
C434	0.18	-0.16	0.01	-0.20	0.12	-0.09	0.07	-0.16	-0.13	0.19	0.02	-0.01	0.15	-0.10
C435	0.10	-0.26	0.16	0.16	0.12	-0.04	-0.02	-0.04	0.06	-0.08	-0.12	-0.10	0.01	0.10
C440	0.05	0.09	0.04	0.20	-0.02	-0.28	-0.03	0.04	0.29	0.17	0.21	0.26	0.49	-0.06
C441	0.17	0.20	0.10	0.13	0.01	-0.13	0.05	0.15	-0.02	-0.07	-0.02	-0.02	-0.18	-0.05
C442	0.12	0.18	0.23	-0.08	0.10	0.16	0.02	-0.04	-0.10	-0.21	0.04	0.18	0.03	0.26
C443	-0.09	0.12	0.16	-0.12	0.08	0.23	-0.26	-0.02	-0.03	-0.06	0.01	0.23	0.25	0.13
C444	**-0.19**	0.02	-0.09	-0.05	0.16	0.11	-0.04	0.09	0.15	-0.11	-0.15	0.29	0.06	-0.07
C445	-0.03	0.06	-0.18	-0.01	0.13	-0.19	0.34	-0.15	0.13	-0.05	0.10	0.20	0.09	0.40
C490	0.08	-0.22	0.09	0.22	-0.03	0.06	0.10	-0.08	-0.01	-0.23	-0.18	0.21	-0.02	-0.17
C497	0.13	-0.08	-0.13	-0.18	-0.16	0.02	0.06	0.05	0.09	0.37	-0.23	0.26	-0.17	0.20
C498	0.11	-0.24	0.10	0.07	0.04	-0.04	0.07	-0.12	-0.02	0.17	-0.25	0.00	0.06	-0.10
C499	0.10	-0.28	0.14	0.21	0.04	0.02	0.06	-0.07	0.02	-0.14	-0.15	0.06	0.01	-0.06
C505	0.16	0.13	0.06	0.08	-0.18	-0.25	0.01	0.28	0.02	0.01	-0.13	0.17	-0.02	0.06
C506	0.12	0.15	0.21	0.03	-0.18	-0.17	0.07	0.24	-0.18	0.09	-0.05	0.05	-0.21	-0.01
C507	0.04	0.10	0.32	0.00	-0.22	-0.02	-0.07	-0.12	-0.20	0.20	0.12	-0.20	0.13	0.04
C508	-0.06	0.05	0.26	-0.09	-0.14	0.12	-0.29	-0.31	0.07	0.16	0.17	-0.09	0.05	0.06
C509	**-0.18**	-0.02	-0.08	-0.08	0.08	0.06	-0.27	-0.14	0.27	-0.07	0.02	0.25	-0.23	-0.10
C510	-0.16	-0.04	-0.22	0.02	0.20	-0.06	0.21	0.21	-0.03	-0.05	0.04	-0.15	-0.01	-0.07
C511	0.06	0.02	0.00	-0.20	0.27	-0.12	0.23	-0.12	-0.29	-0.16	0.34	0.07	0.08	-0.25

Table 4-35. Raw canonical coefficients for color data of controlled atmosphere experiment

Colors	Can1	Can2
C8	0.37	-0.59
C16	-0.46	-0.21
C80	-0.28	0.24
C81	0.11	-0.73
C88	-0.16	0.69
C152	-0.26	-0.17
C153	0.96	0.17
C160	0.25	-0.28
C216	**5.27**	**63.95**
C224	-0.73	0.75
C225	**-1.65**	-0.87
C226	-0.56	2.98
C232	-0.18	1.00
C233	-0.44	0.21
C288	**-3.76**	**-56.93**
C296	-1.07	-3.16
C297	**-2.14**	-0.95
C298	**2.43**	-0.58
C305	-0.26	-0.06
C360	0.71	**11.97**
C361	**-3.50**	**-5.23**
C368	**3.15**	2.02
C369	**4.73**	**4.21**
C370	**-4.03**	0.35
C378	0.06	0.34
C426	**5.05**	2.16
C432	**-2.26**	**4.63**
C433	1.26	1.61
C434	-1.94	2.50
C435	**9.21**	**-9.92**
C440	-0.61	-1.40
C441	-1.14	-0.75
C442	-0.13	-0.61
C443	0.73	-0.10
C444	-0.28	-0.18
C445	-0.87	-0.36
C490	-1.45	**4.72**
C497	0.34	**5.76**
C498	**6.42**	-0.87
C499	**-2.24**	**-7.46**
C505	0.00	0.09
C506	0.03	-0.09
C507	0.04	0.06
C508	0.00	-0.03
C509	0.01	-0.01
C510	0.00	-0.01
C511	0.22	-0.18

Table 4-36. Class means on canonical variables of color data for controlled atmosphere experiment

Treatment	Storage Time (Days)	Can1	Can2	Can3
15%CO_2 + 2%O_2	0	-1.34	-3.18	-1.53
	2	-1.37	-2.86	-1.48
	4	-3.65	-2.65	-3.44
	6	-3.72	-3.39	-8.10
	8	-2.41	-4.21	0.56
	10	-4.46	-2.18	3.29
	12	-3.21	-2.32	4.59
7%CO_2 + 2%O_2	0	-2.58	-2.98	-3.08
	2	-3.85	-4.24	2.44
	4	-5.02	-4.11	-1.97
	6	-3.79	-2.82	-5.94
	8	-4.27	-3.93	1.48
	10	-4.88	2.13	4.08
	12	-2.22	2.31	3.93
Air	0	-2.98	-2.75	-2.48
	2	-1.84	-2.27	2.01
	4	-6.61	4.96	-2.41
	6	-7.25	-5.05	3.68
	8	-5.90	0.09	5.03
	10	-8.00	37.31	-0.90
	12	79.34	2.12	0.22

*8 replications of samples per each storage time

treatment from 7%CO_2 and 15%CO_2 at time 12 days from other time*treatment combinations. Can1 also gave good separation of air treated samples from CO_2 ones at day 12, which means that they deteriorated earlier than CO_2 treated zucchini samples in terms of color changes. However, treatment groups could not be separated from each other from day 0 to day 8 using Can1 and Can2 only. Can3 provided a slight separation between 7% and 15%CO_2 treatments at day 6. As a result, color is not a particularly good discriminator unless one is willing to use a lot of color information to do the classification.

Another approach was tried by combining similar color blocks, which were very close in RGB, to see if we could obtain better separation between treatment groups by time. Colors with 224, 225, 233, and 232 block numbers were combined together as group A because their colors were very close to each other. Colors 368, 369 and 370 was also combined as group B. 440, 441, 442, 443, 444 and 445 as group C and 505, 506, 507,and 508 as group D were all combined separately. Thus total amount of colors were reduced. CDA was performed to see if we can obtain better discrimination between the treatments. It was observed that the first two variables can explain more than 91% of the total variance (Appendix D). It means that the first two canonical variables would do a satisfactory job of describing the separation of treatments by time. Table 4-37 also shows class means on canonical variables of combined color data. Can1 was sufficient to discriminate Air treatment from both CO_2 treatments at day 10, in addition Can1 also provided good discrimination between 7% CO_2 and 15%CO_2 treatments.

Table 4-37. Class means on canonical variables of reduced color data for controlled atmosphere experiment.

Treatment	Storage Time (Days)	Can1	Can2	Can3
$15\%CO_2 + 2\%O_2$	0	-0.94	0.26	-0.34
	2	-0.68	-1.36	-0.57
	4	-0.85	0.20	-0.41
	6	-0.72	-1.07	-1.27
	8	-1.11	1.04	0.09
	10	0.20	-0.47	0.68
	12	-0.25	-0.43	-0.23
$7\%CO_2 + 2\%O_2$	0	-1.02	0.88	-0.23
	2	-0.81	0.26	-0.40
	4	-0.90	0.83	-0.31
	6	-0.76	-0.86	-0.53
	8	-1.12	1.15	0.13
	10	1.58	-1.00	0.70
	12	2.05	-1.07	1.51
Air	0	-1.09	0.99	-0.05
	2	-1.17	0.79	0.30
	4	-0.65	0.43	0.28
	6	-1.04	0.52	1.21
	8	0.05	-0.97	0.66
	10	7.99	1.36	-0.61
	12	1.25	-1.48	-0.64

*8 replications of samples per each storage time

PCA of E-nose Data of Controlled Atmosphere Experiment

Table 4-38 presents the means and variances for the e-nose sensor data of different treated samples. Table 4-39 shows that largest eigenvalue was 11.47. Thus, the first principal component explains about 96% of the total variation. We also observe that first eigenvector (Prin 1 column) having all positive numbers, reveals that the first principal component seems to measure the overall odor from different treated samples (Table 4-40). Because first principal component gives almost same numbers, second principal component is used to define sensors. Sensors with the highest numbers were selected for further correlation analysis (Table 4-40). Associated eigenvalues are 0.64, 0.39 and 0.35 for T_258, T_298 and T_259, respectively. First and second principal component together provided largest variance (98%) of e-nose data. As a result, instead of using 12 sensors, odor can be measured using 3 sensors. It is evident that reduction of dimensionality is very useful here. This behavior of PCA is not surprising since most of the correlations are high

CDA of Sensor Data of Controlled Atmosphere Experiment

Results shows that the first 2 canonical functions are highly significant and can explain more than 80% of total variance (Appendix D). This means that 2 canonical variables would satisfactorily describe the data.

Three canonical variables (Can1 and Can2) are shown in Table 4-41.

The first canonical variable seems to represent a contrast between two groups of sensors. It means that fresh and off-odors detected by sensors can be discriminated using CDA when samples started to decay. First canonical variable mostly affected by T_261,

Table 4-38. Mean and standard deviation of sensor readings used for PCA analysis for controlled atmosphere experiment.

Sensors	Mean[1]	Std Dev[1]	Minimum	Maximum
T_301	3.62	0.42	2.71	4.51
T_298	16.89	1.55	13.86	20.29
T_297	13.95	1.24	11.45	16.74
T_283	9.98	0.87	8.04	12.67
T_278	4.78	0.44	3.76	5.95
T_264	13.65	1.21	10.79	17.97
T_263	10.95	1.18	8.31	15.02
T_262	5.53	0.54	4.09	7.29
T_261	5.65	0.50	4.31	7.39
T_260	8.56	0.71	6.68	10.82
T_259	5.69	0.41	4.55	7.18
T_258	7.26	0.79	5.57	10.03

[1] replications used for mean and st. dev. calculations for e-nose measurements for PCA

Table 4-39. Eigenvalues and percent total variability of the correlation matrix obtained by PCA for e-nose data of controlled atmosphere experiment.

Principal components	Eigenvalue	Difference	Proportion	Cumulative
1	**11.47**	**11.18**	**0.95**	**0.96**
2	**0.28**	**0.12**	**0.02**	**0.98**
3	0.16	0.12	0.01	0.99
4	0.03	0.01	0.00	1.00
5	0.02	0.01	0.00	1.00
6	0.01	0.00	0.00	1.00
7	0.01	0.00	0.00	1.00
8	0.00	0.00	0.00	1.00
9	0.00	0.00	0.00	1.00
10	0.00	0.00	0.00	1.00
11	0.00	0.00	0.00	1.00
12	0.00	-	0.00	1.00

Table 4-40. Eigenvectors (PCA coefficients) from e-nose data set of controlled atmosphere experiment.

Sensors	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6
T_301	**0.29**	-0.28	0.22	-0.30	0.08	0.79
T_298	**0.29**	**-0.39**	0.33	0.11	-0.20	-0.17
T_297	**0.29**	-0.34	0.30	0.14	-0.16	-0.24
T_283	**0.29**	-0.09	-0.07	0.25	-0.07	0.01
T_278	**0.29**	-0.16	0.09	-0.27	0.34	-0.40
T_264	**0.29**	-0.02	-0.40	0.36	-0.06	-0.09
T_263	**0.29**	-0.12	-0.44	0.42	0.12	0.27
T_262	**0.29**	0.10	-0.18	-0.30	0.52	-0.05
T_261	**0.29**	0.18	-0.16	-0.20	0.16	-0.16
T_260	**0.29**	0.15	-0.04	-0.27	-0.35	-0.12
T_259	**0.29**	**0.35**	-0.16	-0.28	-0.58	0.07
T_258	**0.27**	**0.64**	0.55	0.39	0.19	0.09

Table 4-41. Raw canonical coefficients for e-nose sensors of controlled atmosphere experiment

Sensors	Can1	Can2
T_301	-9.35	7.25
T_298	8.11	1.17
T_297	5.22	-3.81
T_283	-21.14	-2.92
T_278	3.46	5.78
T_264	11.91	10.71
T_263	5.36	-4.18
T_262	-2.99	-9.48
T_261	-22.64	-4.99
T_260	-5.01	1.31
T_259	3.74	-11.77
T_258	-2.71	7.77

T_264, T_283, T_301, and T_298. The second canonical variable is influenced by T_264, T_259, T_262, T_258 and T_301.

Sensors were also used to discriminate treatments over time. Results showed that about 2 sensor functions to be able to separate these groups. Each sensor function is typically very effective of separating one or two time treatment *time combinations from others (Table 4-42). For example, Can1 is very effective in explaining Air and both 7% and 15% CO_2 samples to decay after day 6. Can 2 gave good separation on all treatments at days 10 and 12. Can2 also gave the information about protecting the highest quality using different CA conditions. Air samples gave higher discrimination than other treatments. As a result, sensor readings for odor analysis are good discriminators for quality analysis. This can be observed from reduced sensor evaluation, too. Twelve sensors were reduced to 3 sensors to see if we could obtain better separation between treatment groups by time. It was observed that the first two variables can also explain more than 98% of the total variance. First canonical function explains 71% of the total variation. It means that first two canonical variables would satisfactorily describe the separation of treatments by time, too. Associated results are shown in Appendix D. Table 4-43 shows class means of canonical variables of reduced sensor data. Can1 was enough to discriminate treatments at days 10 and 12 when reduced sensor was used. When evaluating T_258, T_259 and T_298 separation by time, can1 was very effective in separating treatment groups as well as Can2. They all showed a similar separation trend. However, T-258 sensor on treatments was discriminated better in both can 1 and can2 functions over time. In summary, all sensors can be used for data analysis. On the other

Table 4-42. Class means on canonical variables of e-nose data for controlled atmosphere experiment

Treatments	Storage Time (Days)	Can1	Can2
$15\%CO_2 + 2\%O_2$	0	7.43	0.98
	2	3.48	-1.67
	4	-0.01	-2.69
	6	-3.49	-2.35
	8	-3.64	-1.73
	10	-4.56	1.08
	12	-3.39	0.33
$7\%CO_2 + 2\%O_2$	0	10.24	1.88
	2	5.15	-1.86
	4	0.87	-2.53
	6	-2.60	-2.90
	8	-4.23	-2.13
	10	-5.78	0.26
	12	-4.57	1.35
Air	0	13.99	2.97
	2	5.66	-1.22
	4	1.78	-1.89
	6	-2.08	-1.75
	8	-4.63	-0.22
	10	-6.63	5.47
	12	-2.99	8.63

*5 replications of samples per each storage time

Table 4-43. Class means on canonical variables of reduced sensor data for controlled atmosphere experiment

Treatment	Storage Time (Days)	Can1	Can2
15%CO_2 + 2%O_2	0	4.14	3.00
	2	1.82	-1.01
	4	0.92	-1.55
	6	0.07	-1.60
	8	0.24	-0.65
	10	-2.08	0.22
	12	-2.36	-1.29
7%CO_2 + 2%O_2	0	5.25	3.92
	2	2.94	-0.01
	4	1.79	-0.98
	6	0.15	-2.33
	8	-0.06	-1.55
	10	-1.88	-0.20
	12	-3.16	-0.34
Air	0	5.56	3.64
	2	2.58	-1.23
	4	1.51	-1.71
	6	-0.44	-1.96
	8	-2.23	-1.04
	10	-7.38	2.40
	12	-7.39	4.25

hand using 3 sensors instead of 12 can also provide enough information for a good discrimination for quality purposes. This can reduce the cost and time of quality analysis.

Canonical Correlation for Controlled Atmosphere Experiment

Specific correlations between objective readings obtained from electronic nose, machine vision and Instron and organoleptic evalutions given by trained panelists were performed. Table 4-44 shows summarized correlation results for CA experiment. For canonical correlation between color data and sensory, reduced color blocks (from 47 to 13) obtained from PCA and sensory color descriptors were correlated. Two sets of variables, color and sensory data (yellow and green of peel color, and browning and discoloration of flesh color), are separately specified, sensory data listed in VAR (v) statement and the color data in the WITH (w) statement in the canonical analysis. Associated F statistics showed that there is a strong relationship between color and sensory data over time. There is a good linear relation between sensory data and color data (r=0.99). Associated results are presented in Appendix E.

As a result, the color changes over time was observed by color machine vision as well as sensory panelists.

Canonical correlation analysis and F statistics shows that there is a significant canonical correlation between e-nose and sensory data (Table 4-44). There is highly positive canonical correlation between off-odor and sensor types of T_283, T_261 and T_297. Off-odor was negatively correlated with T_298, T_262, T_263, and T_264. It means that when the panelists reported the formation of off-odor over time, T_283, T_261 and T_297 sensors from e-nose also gave high readings. Results were shown in

Table 4-44. The canonical correlation between objective readings and sensory evaluations in controlled atmosphere experiment.

Objective readings	Sensory evaluations							
	Color (Yellow, green and discoloration)		Odor (Fresh zucchini aroma and off-odor)		Texture (Hardness-Crispness)		Microbial growth	
	r	P- value	r	P-value	r	P-value	r	P-value
Machine vision	0.99	0.03	—	—	—	—	—	—
E-nose (all)	—	—	0.97	0.02	—	—	0.99	0.01
E-nose (reduced)	—	—	0.86	0.01	—	—	0.94	0.01
Microbial count	—	—	0.92	0.01	—	—	—	—
Instron	—	—	—	—	0.87	0.01	—	—

Appendix E. Canonical correlation between the first pair of e-nose and sensory data gave a good linear relationship.

Odor related sensory attributes were also correlated with readings of reduced sensors from PCA to see if there is a better correlation. Correlation was significant (Table 4-44). It was also observed that very good correlation between fresh zucchini aroma was given by panelists and T-298 sensor (Appendix E). Changes in odor as a quality characteristic were observed by e-nose as well as by panelists.

Table 4-44 also showed that significant canonical correlation between sensor readings from e-nose and microbial count data was obtained. High positive correlation between microbial count and T_297, T_283, T_261, T_259 sensors was obtained. Microbial count gave high negative canonical correlation with T_298, T_264, T_262 and T_260 (Appendix E). Canonical correlation analysis was repeated using reduced sensors obtained from PCA analysis to see if there is any increase or decrease in correlation. Results showed a good relation between variables. E-nose can also provide information about microbial growth in storage studies (Table 4-44).

Canonical correlation between smell related sensory attributes and microbial count show that there is significant canonical correlation between smell related sensory descriptors and microbial count (Table 4-44). There is a positive linear relation between microbial count and off-odor. However, microbial count had negative relation with fresh zucchini aroma (Appendix E).

Texture related sensory descriptors and maximum shear force measured was also correlated. There was only one significant canonical correlation between variables that maximum shear force obtained by cutting with blade had high positive correlation with hardness, but maximum shear force obtained by compression using probe gave low correlation with sensory attributes of hardness and crispness (Appendix E) (Table 4-44).

Principal Component Analysis (PCA) and Canonical Discrimination Analysis (CDA) for Experiment I

PCA Color Data of Experiment I

The means and variances for the %colors of different treated samples are presented in Table 4-45 . The cumulative variance reached 83% at the 13th eigenvalue, so the first 13 principal components should be used to describe the data. It is clear that 13 colors out of 30 are enough to use for correlation analysis with color descriptors given by trained panelists (Table 4-46 and 4-47).

CDA of Color Data of Experiment I

Same CDA procedure explained in CA study was used to analyze the data from experiment I. Three canonical variables would be used describing color the data with 51% of total variation. Significant F statistics was obtained with canonical variables (Appendix D).

The coefficients of canonical variables (Can1, Can2 and Can3) are shown in Table 4-48. We observe about 3 color functions can be enough to separate treatments by time groups. Each color function is very effective in separating one or two time treatment *time combinations from all others (Table 4-49). For example, Can1 is very effective in separating P1-Air and P2-Air treatments from P1-CO_2 and P2-CO_2 treatments at time 22 and 24 days from other time*treatment combinations. However, treatment groups could not be separated well from each other from day 0 to day 17 using Can1 and Can2 only. Can3 provided slight separation between P1 and P2 -Air samples at day 6 and day 17

Table 4-45. Mean and standard deviation of colors used for PCA analysis for experiment I.

Color	Mean(%)[1]	Std Dev[1]	Minimum	Maximum
c81	0.02	0.17	0.00	2.42
c152	0.03	0.23	0.00	2.45
c153	0.27	0.62	0.00	5.23
c154	0.32	0.63	0.00	4.18
c160	0.03	0.19	0.00	2.47
c161	0.12	0.30	0.00	2.46
c162	0.13	0.29	0.00	2.21
c218	0.02	0.13	0.00	2.11
c224	0.10	0.30	0.00	2.64
c225	1.20	0.75	0.00	3.73
c226	1.94	0.86	0.23	5.90
c227	0.69	0.48	0.00	3.08
c233	0.41	0.44	0.00	3.00
c234	0.88	0.43	0.00	2.53
c235	0.07	0.24	0.00	2.15
c297	0.25	0.38	0.00	2.15
c298	1.73	0.52	0.39	3.80
c299	1.51	0.46	0.40	3.27
c371	1.44	0.39	0.34	2.57
c372	1.05	0.32	0.26	2.03
c443	0.50	0.52	0.00	2.77
c444	2.46	0.49	0.77	3.94
c445	1.66	0.51	0.49	3.13
c446	1.21	0.30	0.52	2.15
c506	0.02	0.24	0.00	4.76
c507	0.10	0.96	0.00	12.53
c508	1.95	2.99	0.09	38.78
c509	14.88	4.43	5.53	43.83
c510	55.00	8.43	1.44	71.78
c511	3.12	5.30	0.00	30.27

[1] 12 replications used for mean and st. dev. calculations for color measurements for PCA

Table 4-46. Eigenvalues and percent total variability of the correlation matrix obtained by PCA for color data set of experiment I.

Principal components	Eigenvalue	Proportion	Cumulative
1	5.20	0.17	0.17
2	3.46	0.12	0.29
3	3.31	0.11	0.40
4	2.22	0.07	0.47
5	1.99	0.07	0.54
6	1.43	0.05	0.59
7	1.42	0.05	0.63
8	1.29	0.04	0.68
9	1.25	0.04	0.72
10	0.98	0.03	0.75
11	0.93	0.03	0.78
12	0.73	0.02	0.81
13	0.71	0.02	0.83
14	0.60	0.02	0.85
15	0.58	0.02	0.87
16	0.52	0.02	0.89
17	0.47	0.02	0.90
18	0.39	0.01	0.92
19	0.37	0.01	0.93
20	0.34	0.01	0.94
21	0.33	0.01	0.95
22	0.30	0.01	0.96
23	0.26	0.01	0.97
24	0.22	0.01	0.98
25	0.21	0.01	0.98
26	0.17	0.01	0.99
27	0.15	0.01	0.99
28	0.14	0.00	1.00
29	0.05	0.00	1.00
30	0.01	0.00	1.00

Table4-47. Eigenvectors (PCA coefficients) from color data of zucchini experiment I

	Eigenvectors												
Color block#	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10	Prin11	Prin12	Prin13
c81	0.07	0.21	0.12	-0.23	0.00	0.16	0.07	-0.12	0.37	-0.37	0.12	0.34	-0.12
c152	0.13	0.00	0.23	-0.22	-0.15	0.31	-0.02	-0.16	0.12	0.32	-0.27	-0.17	0.25
c153	0.18	0.18	0.29	-0.25	-0.09	0.17	-0.02	-0.10	0.28	-0.01	-0.01	-0.07	0.04
c154	**0.18**	0.32	0.20	-0.17	0.08	0.08	0.08	-0.02	0.03	-0.07	0.13	0.10	0.03
c160	0.11	-0.08	0.26	0.04	-0.07	0.05	-0.31	0.28	-0.10	0.24	0.38	-0.18	0.06
c161	0.11	0.03	0.31	0.14	0.11	-0.12	-0.34	0.23	0.08	0.03	0.21	-0.14	-0.10
c162	0.09	0.13	0.18	0.18	0.22	-0.10	-0.38	0.11	-0.01	-0.10	0.04	0.40	0.12
c218	0.04	0.22	0.01	-0.23	0.06	-0.06	0.39	0.32	-0.14	-0.11	0.34	-0.11	0.03
c224	**0.22**	-0.20	0.16	-0.12	-0.16	0.14	0.00	-0.01	-0.19	0.23	0.02	0.22	0.15
c225	**0.18**	-0.06	0.25	0.18	-0.06	-0.21	0.36	0.11	0.05	-0.03	-0.26	-0.07	-0.12
c226	**0.19**	0.24	0.07	0.15	0.19	-0.18	0.33	0.09	-0.25	0.05	-0.05	0.14	0.15
c227	0.13	0.19	0.07	0.08	0.31	0.10	0.11	-0.23	-0.36	0.31	0.00	0.08	0.04
c233	0.12	-0.18	0.11	0.35	-0.14	0.09	0.13	0.00	0.07	-0.39	0.22	-0.13	0.06
c234	-0.01	0.02	-0.05	0.48	0.17	0.25	-0.01	-0.21	0.15	0.04	0.02	0.22	0.15
c235	-0.08	-0.03	-0.03	0.16	0.18	0.49	0.17	-0.11	0.04	0.18	0.30	-0.18	-0.49
c297	**0.23**	-0.26	-0.12	0.00	-0.15	0.14	0.05	0.00	-0.09	-0.20	0.19	-0.01	0.28
c298	0.02	0.21	-0.36	0.12	-0.04	0.17	-0.01	0.04	0.08	0.04	0.21	0.03	0.30
c299	**0.27**	-0.14	-0.03	-0.11	0.09	0.13	0.23	0.25	0.10	0.21	0.18	0.18	0.19
c371	-0.01	0.32	-0.34	-0.05	-0.01	0.05	-0.12	0.20	0.10	0.10	-0.06	-0.03	0.12
c372	**-0.29**	-0.21	0.05	-0.20	0.06	-0.02	0.08	0.22	0.09	0.07	0.10	0.20	0.16
c443	**0.28**	-0.18	-0.16	0.05	-0.22	0.13	0.00	0.00	-0.09	-0.06	0.00	0.08	0.20
c444	0.05	0.31	-0.18	0.21	-0.14	-0.02	-0.06	0.23	0.31	0.17	-0.14	-0.15	0.03
c445	**-0.33**	-0.14	0.11	-0.06	0.17	-0.04	-0.10	-0.12	0.05	0.02	0.03	0.20	0.04
c446	-0.06	-0.16	0.23	0.26	0.08	-0.02	0.28	0.20	0.39	0.16	-0.15	0.02	0.17
c506	0.15	-0.14	-0.13	-0.14	0.41	-0.15	-0.03	-0.08	0.22	0.00	0.05	-0.36	0.19
c507	**0.22**	-0.20	-0.14	-0.15	0.41	-0.13	-0.02	-0.07	0.18	0.02	0.02	-0.08	0.05
c508	**0.31**	-0.19	-0.20	-0.10	0.20	-0.07	-0.03	-0.05	0.07	-0.01	0.03	0.10	-0.11
c509	**0.21**	-0.12	-0.19	-0.03	-0.24	-0.15	0.00	0.14	0.14	0.29	0.07	0.33	-0.40
c510	**-0.32**	0.12	0.09	0.03	-0.17	-0.22	-0.01	-0.33	-0.04	-0.01	0.20	-0.18	0.19
c511	-0.09	-0.05	0.01	-0.06	0.21	0.44	-0.13	0.41	-0.23	-0.30	-0.40	-0.08	-0.06

Table 4-48. Raw canonical coefficients for color blocks of experiment I

Colors	Can1	Can2	Can3
c81	0.15	0.08	-0.78
c152	0.88	-0.78	-0.66
c153	0.70	0.90	0.36
c154	0.16	**-1.09**	0.53
c160	**1.19**	-0.51	0.13
c161	0.84	-0.41	-0.80
c162	0.15	-0.33	**-1.07**
c218	**-2.09**	**8.89**	**1.54**
c224	**1.08**	-0.16	-0.11
c225	0.74	-0.24	-0.33
c226	0.45	0.43	0.38
c227	0.23	-0.14	-0.28
c233	0.26	-0.88	**1.28**
c234	0.67	**-1.11**	-0.83
c235	-0.23	**-1.73**	**6.90**
c297	**3.55**	**1.03**	0.37
c298	0.05	0.10	0.07
c299	0.46	0.44	-0.19
c371	**1.36**	0.60	0.29
c372	0.68	**1.20**	0.20
c443	**2.27**	-0.61	0.01
c444	0.12	-0.61	-0.25
c445	0.32	**-1.10**	-0.54
c446	**1.29**	**-1.36**	0.85
c506	-0.29	**-1.00**	0.10
c507	0.83	0.11	0.00
c508	0.21	-0.29	0.11
c509	0.40	-0.17	0.08
c510	0.40	-0.18	0.09
c511	0.42	-0.18	0.12

Table 4-49. Class means on canonical variables of color data for experiment I

Treatment	Time	Can1	Can2	Can3
P1-Air	0	-1.16	-1.72	-0.62
	3	1.09	-0.94	0.08
	6	0.24	-2.03	5.79
	8	0.28	-0.82	-1.24
	10	-0.77	-1.04	1.99
	13	-2.29	-1.86	3.73
	15	0.13	0.99	-0.94
	17	-2.25	-1.86	2.78
	22	2.43	0.44	-0.30
	24	2.18	-0.36	-0.61
P1-CO$_2$	0	1.92	-0.18	-0.37
	3	-1.88	-1.09	-1.26
	6	-2.45	-0.22	-1.54
	8	-2.01	-0.82	-1.89
	10	1.37	1.23	-1.04
	13	-2.11	-1.00	-1.26
	15	-1.58	0.62	-0.57
	17	-0.64	-0.97	-0.21
	22	-0.40	-0.42	-0.36
	24	3.97	-0.66	-0.30
P2-Air	0	-0.39	-0.67	-0.47
	3	1.81	-0.07	0.45
	6	-3.31	10.01	2.27
	8	-2.11	-0.54	-0.95
	10	-0.85	-0.27	-1.29
	13	1.47	-0.43	-0.70
	15	-1.74	-0.52	-0.58
	17	0.94	-0.97	3.68
	22	2.81	1.59	-0.24
	24	2.77	0.75	0.03
P2-CO$_2$	0	1.92	0.82	0.23
	3	-1.94	-0.71	-0.66
	6	-1.13	0.48	-0.80
	8	-1.04	-0.76	-0.20
	10	-1.96	0.87	-0.71
	13	1.58	0.71	0.09
	15	-1.34	-0.43	-1.58
	17	0.26	0.28	-0.58
	22	2.81	1.99	0.16
	24	3.38	0.61	-0.02

from P1 and P2-CO_2 treatments. In this experiment, it is clear color is not a good discriminator unless one is willing to use a lot of color information to do the classification.

Another approach was tried by combining similar color blocks to see if we could obtain better separation between treatment groups by time. Combined similar color blocks were named in A (C371+C372), B(C443+C444+C445+C446) and C (506+C057+C508) groups. Reduced color data was analyzed using CDA. Results show that the first two canonical variables can explain more than 90% of the total variance (Appendix D). The first two canonical variables would describe the separation of treatments by time using reduced colors in the data set (Table 4-50). Table 4-51 shows class means of canonical variables of combined color data. Can1 and Can2 gave better discrimination between P1 and P2-Air treatments and P1 and P2- CO_2 treatments. Results shows that P2-Air had the earlier decay followed by P1-Air.

PCA of E-nose Data of Experiment I

The means and variances for the e-nose sensor data of different treated samples are shown in Table 4-52. Since the cumulative variance reached 96% at the second principal component, 2 principal components must be used to describe the data (Table 4-53). According to highest associated eigenvalues in second principal component, 3 sensors (T_264, T_258 and T_262) out of 12 were chosen to measure odor of samples. These 3 sensors can also provide better correlation with sensory data (Table 4-54).

CDA of E-nose Data of Experiment I

Two functions would be enough to explain 60% of the total variation in the e-nose data set. Results were shown in Appendix D. The raw canonical coefficients of canonical

Table 4-50. Raw canonical coefficients for reduced color blocks of experiment I

Colors	Can1	Can2
A	0.20	-0.13
B	2.02	0.74
C	-2.06	1.99

Table 4-51. Class means of canonical variables of reduced color data for experiment I

Treatment	Time	Can1	Can2
P1-Air	0	1.98	0.47
	3	0.42	-0.54
	6	0.40	-0.65
	8	0.16	-0.57
	10	0.20	0.10
	13	-0.05	0.26
	15	-0.98	0.46
	17	-0.17	-0.27
	22	0.05	-0.55
	24	-0.02	-1.07
P1-CO_2	0	1.44	0.93
	3	-0.17	-0.58
	6	-0.03	-0.55
	8	0.21	0.01
	10	-0.09	0.38
	13	0.90	0.17
	15	-0.89	-0.18
	17	0.94	-0.08
	22	0.06	-0.96
	24	0.81	-0.48
P2-Air	0	0.86	0.02
	3	0.15	-1.35
	6	-4.14	0.84
	8	-1.03	0.10
	10	0.41	0.84
	13	1.15	1.08
	15	-1.03	-0.04
	17	-0.02	0.76
	22	-1.18	0.28
	24	-0.10	0.36
P2-CO_2	0	0.20	-0.20
	3	0.33	-0.99
	6	-1.27	-0.53
	8	1.15	0.82
	10	-0.80	0.42
	13	-0.01	0.00
	15	0.75	0.81
	17	-0.32	0.34
	22	-0.50	0.14
	24	0.23	0.00

Table 4-52. Mean and standard deviation of sensor readings used for PCA analysis for experiment I

Sensors	Mean (%)	Std Dev	Minimum	Maximum
T_301	3.12	0.19	2.50	3.53
T_298	15.73	0.75	13.48	17.31
T_297	14.20	0.66	12.13	15.63
T_283	8.08	0.33	6.90	8.88
T_278	4.48	0.18	3.70	4.91
T_264	14.18	0.58	11.94	16.17
T_263	9.79	0.50	7.85	11.06
T_262	4.56	0.29	3.49	5.19
T_261	5.96	0.28	4.93	6.63
T_260	7.06	0.33	5.92	7.80
T_259	4.79	0.22	4.09	5.32
T_258	7.22	0.31	6.25	7.89

Table 4-53. Eigenvalues and percent total variability of the correlation matrix obtained by PCA for e-nose data set of experiment I

Principal components	Eigenvalue	Difference	Proportion	Cumulative
1	**10.84**	**10.19**	**0.90**	**0.90**
2	**0.65**	**0.41**	**0.05**	**0.96**
3	0.24	0.13	0.02	0.98
4	0.11	0.04	0.01	0.99
5	0.06	0.01	0.01	0.99
6	0.06	0.03	0.00	1.00
7	0.02	0.01	0.00	1.00
8	0.01	0.00	0.00	1.00
9	0.01	0.00	0.00	1.00
10	0.01	0.00	0.00	1.00
11	0.00	0.00	0.00	1.00
12	0.00	-	0.00	1.00

variables (Can1 and Can2) are shown in Table 4-55. Attempting to use sensor discrimination among treatments by time we observe that 2 sensor functions are able to separate these groups. Can1 and Can2 gave good separation of P1-Air and P1-CO_2 treatments (Table 4-56). Can2 also shows that P2-Air decayed earlier than other treatments. Results indicated that P2-CO_2 samples provided better quality on odor than other treatment. This can be observed from reduced sensor evaluations. Twelve sensors were reduced to 3 sensors. The first two variables explain more than 87% of the total variance (Appendix D). Table 4-57 shows class means of canonical variables of reduced sensor data. It means that first two canonical variables were enough to describe the separation of treatments by time. In summary, all sensors can be used for data analysis, but using 3 sensors instead of 12 can provide enough information for a good discrimination between treatments over time. This can reduce the cost and time for quality analysis.

Canonical Correlation for Experiment I

Canonical correlation between objective and organoleptic variables were shown in Table 4-58. Color blocks reduced from 30 to14 using PCA and selected sensory color descriptors were correlated. Two sets of variables, color and sensory data (White-yellow and degree of transparency), are specified (Appendix E). One significant canonical correlation was observed. There is a high positive significant correlation between color descriptors (degree of transparency, white-yellow) and color blocks (c224 (strong yellow green), c372 (light yellow green) and c508 (light greenish yellow)). A high negative correlation between white-yellow descriptor and same color blocks (Appendix E). Another good linear relation was obtained between white-yellow color descriptor and

Table 4-54. Eigenvectors (PCA coefficients) from e-nose data set of experiment I

Sensors	Prin1	Prin2
T_301	**0.29**	-0.06
T_298	**0.29**	-0.35
T_297	**0.29**	-0.30
T_283	**0.30**	0.01
T_278	**0.29**	0.03
T_264	**0.27**	**0.46**
T_263	**0.28**	0.43
T_262	**0.27**	**0.44**
T_261	**0.30**	0.09
T_260	**0.30**	-0.12
T_259	**0.29**	-0.20
T_258	**0.28**	**-0.37**

Table 4-55. Raw canonical coefficients for e-nose sensors of experiment I

Sensors	Can1	Can2
T_301	-20.09	3.06
T_298	-0.63	-0.86
T_297	9.88	-5.59
T_283	-15.49	6.27
T_278	-1.77	-2.29
T_264	-1.88	-1.54
T_263	13.22	1.13
T_262	-10.84	10.65
T_261	0.11	5.47
T_260	-24.12	-24.26
T_259	45.54	-11.95
T_258	-2.14	26.93

Table 4-56. Class means on canonical variables of e-nose data for experiment I

Treatments	Time	Can1	Can2
P1-Air	0	7.29	-2.88
	3	-4.80	-1.96
	6	-1.19	0.99
	8	0.76	0.22
	10	-1.58	-1.30
	13	5.60	-2.66
	15	2.71	0.09
	17	1.79	0.08
	22	4.09	2.62
	24	3.28	4.55
P1-CO_2	0	5.46	-5.67
	3	-5.27	-1.03
	6	-3.43	0.68
	8	-0.22	-1.15
	10	-3.64	-2.03
	13	3.38	-2.53
	15	0.77	-0.99
	17	-1.52	1.95
	22	3.43	3.70
	24	2.44	6.36
P2-Air	0	3.38	-3.37
	3	-5.05	-1.20
	6	-3.67	-0.29
	8	-1.58	-1.31
	10	-4.32	-1.13
	13	2.87	-1.89
	15	-0.22	-0.39
	17	-1.29	1.19
	22	1.15	3.98
	24	0.43	4.10
P2-CO_2	0	1.76	-4.69
	3	-3.22	-2.69
	6	-4.81	1.04
	8	-1.04	-0.10
	10	-4.80	-1.53
	13	1.75	-1.92
	15	-0.30	0.11
	17	-1.35	1.77
	22	0.48	3.75
	24	0.50	5.52

Table 4-57. Class means on canonical variables of reduced sensor data for experiment I

Treatments	Storage Time (Days)	Can1	Can2
P1-Air	0	-3.71	1.48
	3	1.94	2.10
	6	1.20	1.22
	8	-0.43	-0.96
	10	0.12	-0.45
	13	-2.58	2.05
	15	-0.39	-1.02
	17	1.11	-0.06
P1-CO_2	0	-2.75	0.84
	3	0.77	1.10
	6	1.30	-0.22
	8	-0.86	-1.41
	10	0.96	-1.07
	13	-3.46	-0.08
	15	0.23	-0.59
	17	2.34	0.11
P2-Air	0	-2.07	-0.24
	3	1.95	1.16
	6	1.63	-0.45
	8	-0.45	-1.31
	10	1.55	-0.02
	13	-1.04	-0.75
	15	0.45	-0.34
	17	1.49	0.46
P2-CO_2	0	-2.53	0.76
	3	0.77	1.96
	6	1.79	-0.55
	8	-0.68	-2.06
	10	1.47	-0.76
	13	-2.22	-0.94
	15	0.63	-0.95
	17	1.47	1.00

color blocks (c154 (dark yellowish green), c297 (strong yellow green) and c509 (pale greenish yellow)) (Appendix E). During storage, color of zucchini flesh changed from white to yellow, followed by a transparent appearance because of the degeneration of the structure.

Canonical correlation analysis shows that there is a significant canonical correlation between e-nose and sensory data. There is high positive canonical correlation between off-odor and sensor types T_283, T_258 and T_298. Fresh zucchini aroma was negatively correlated with the same sensors. Off-odor was negatively correlated with T_264, T_260 and T_297 (Associated results in Appendix E).

Odor related sensory attributes were also significantly correlated with readings of reduced sensors from PCA. There is a high positive correlation between T_258, T_263 sensors and off-odor. Off-odor showed negative correlation with T_298 and T-262. Very good correlation between fresh zucchini aroma values given by panelists and T-298 and T_262 sensor were observed (Appendix E). As a result, changes in odor as a quality characteristic was observed by e-nose as well as by panelists.

Significant canonical correlation between sensor readings from e-nose and microbial count data was significant (Table 4-58). High positive correlation between microbial count and T_298, T_259, T_261, T_263 sensors was obtained. Microbial count gave high negative canonical correlation with T_297, T_260, T_264 and T_301 (Appendix E). Canonical correlation analysis was repeated using reduced sensors obtained from PCA analysis. Results indicated a significant relationship between variables, too. Using 5 sensors instead of 12 did not increase the correlation coefficient.

Table 4-58. The canonical correlation between objective readings and sensory evaluations in experiment I.

Objective readings	Sensory evaluations							
	Color (whiteness-yellowness)		Odor (Fresh zucchini aroma and off-odor)		Texture (Hardness-Crispness)		Microbial growth	
	r	P-value	r	P-value	r	P-value	r	P-value
Machine vision	0.90	0.01	—	—	—	—	—	—
E-nose (all)	—	—	0.94	0.01	—	—	0.95	0.01
E-nose (reduced)	—	—	0.71	0.01	—	—	0.69	0.01
Microbial count	—	—	0.83	0.01	—	—	—	—
Instron	—	—	—	—	0.61	0.01	—	—

There is also significant linear relation between smell related sensory descriptors and microbial count (Table 4-58).

Texture related sensory descriptors given by trained panelists and maximum shear force measured using Instron was significantly correlated (Table 4-58). Maximum shear force obtained by cutting with big blade had high positive correlation with hardness but high negative correlation with dryness / wetness and crispness (Appendix E). Small blade showed negative correlation with hardness and good linear relation with crispness and dryness / wetness descriptors (Appendix E). Another approach was tried to increase correlation. Only two descriptors, hardness and crispness, were correlated with Instron using small and big blades. However, the correlation was not significant ($p<0.26$) (Appendix E).

Principal Component Analysis (PCA) and Canonical Discrimination Analysis (CDA) for Experiment II

PCA of Color Data of Experiment II

Results were shown in Tables 4-59, 4-60 and 4-61. The cumulative variance reached 88% at the 13th eigenvalue, so the first 13 principal components should be used to describe the color data. Since the first principal component explains about 31% of total variability, 13 colors were selected from first principal component column according to their higher eigenvalues. The results of PCA suggests that the 13 colors highlighted in column1 in Table 4-61 provide a good discriminator for quality analysis.

CDA of Color Data of Experiment II

F statistics and cumulative eigenvalues indicated that 2 canonical variables provide 58% of the variability of describing color data (Appendix D).

Table 4-59. Mean and standard deviation of colors used for PCA analysis for experiment II.

Colors	Mean (%)[1]	Std. dev.[1]	Minimum	Maximum
c152	0.04	0.19	0.00	2.43
c153	0.18	0.40	0.00	2.42
c154	0.17	0.44	0.00	3.48
c224	0.13	0.41	0.00	3.01
c225	0.81	0.78	0.00	6.31
c226	1.09	0.67	0.00	3.26
c227	0.29	0.39	0.00	2.11
c233	0.27	0.39	0.00	2.13
c296	0.08	0.30	0.00	2.75
c297	0.43	0.76	0.00	4.71
c298	1.45	0.59	0.01	3.51
c299	1.35	0.47	0.31	2.70
c369	0.25	0.70	0.00	5.28
c370	0.61	0.75	0.00	4.67
c371	1.35	0.46	0.26	3.25
c372	1.08	0.49	0.00	3.29
c433	0.05	0.31	0.00	3.75
c434	0.05	0.41	0.00	5.56
c441	0.15	0.58	0.00	4.94
c442	0.64	1.93	0.00	15.08
c443	0.95	0.98	0.00	8.50
c444	1.99	0.72	0.00	3.83
c445	1.55	0.55	0.45	3.76
c446	1.23	0.33	0.51	3.26
c505	0.08	0.53	0.00	6.62
c506	1.17	4.19	0.00	30.64
c507	2.65	6.62	0.00	38.12
c508	5.48	8.94	0.01	47.14
c509	13.62	9.32	0.09	48.21
c510	38.55	19.33	0.80	70.17
c511	14.91	15.40	0.00	55.36

[1] 12 replications used for mean and st. dev. calculations for color measurements for PCA

Table 4-60. Eigenvalues and percent total variability of the correlation matrix obtained by PCA for color data set of experiment II.

Principal components	Eigenvalue	Proportion	Cumulative
1	9.73	0.31	0.31
2	3.39	0.11	0.42
3	2.94	0.09	0.52
4	2.32	0.07	0.59
5	2.00	0.06	0.66
6	1.46	0.05	0.70
7	1.12	0.04	0.74
8	1.06	0.03	0.77
9	0.84	0.03	0.80
10	0.65	0.02	0.82
11	0.62	0.02	0.84
12	0.57	0.02	0.86
13	0.56	0.02	0.88
14	0.51	0.02	0.90
15	0.44	0.01	0.91
16	0.41	0.01	0.92
17	0.32	0.01	0.93
18	0.31	0.01	0.94
19	0.28	0.01	0.95
20	0.26	0.01	0.96
21	0.22	0.01	0.97
22	0.18	0.01	0.97
23	0.16	0.01	0.98
24	0.16	0.01	0.98
25	0.12	0.00	0.99
26	0.11	0.00	0.99
27	0.09	0.00	1.00
28	0.07	0.00	1.00
29	0.05	0.00	1.00
30	0.03	0.00	1.00
31	0.00	0.00	1.00

Table 4-61. Eigenvectors (PCA coefficients) from color data set of zucchini experiment II

Color Blocks	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10	Prin11	Prin12	Prin13
c152	0.02	-0.07	0.24	0.17	0.26	-0.27	0.04	0.45	0.26	0.32	-0.13	-0.08	0.06
c153	-0.01	-0.10	0.41	0.02	0.01	-0.13	0.02	0.30	0.03	0.04	0.53	-0.26	-0.01
c154	-0.04	-0.17	0.31	0.17	-0.14	0.14	0.06	0.05	0.28	-0.13	0.26	0.58	-0.33
c224	**0.20**	0.03	0.07	-0.31	0.11	0.27	0.07	0.02	-0.11	0.10	0.04	0.29	0.06
c225	0.18	-0.07	0.28	0.10	0.32	0.04	-0.07	0.02	-0.26	-0.18	-0.05	-0.01	0.12
c226	0.06	-0.20	0.30	0.26	0.02	0.22	-0.02	-0.35	-0.12	-0.10	-0.12	0.00	0.25
c227	0.02	-0.18	0.24	0.24	-0.09	0.20	0.06	-0.32	0.27	0.52	-0.31	-0.13	0.02
c233	**0.18**	-0.08	0.08	0.06	0.37	-0.11	0.10	-0.05	-0.12	0.02	-0.06	0.12	-0.22
c296	**0.20**	0.09	0.11	-0.31	0.02	0.29	0.19	0.02	0.15	0.03	0.03	0.10	0.12
c297	**0.29**	0.02	-0.08	0.07	0.10	-0.04	-0.03	0.03	0.01	-0.02	-0.15	0.04	-0.18
c298	0.11	-0.03	-0.16	0.36	-0.09	0.25	0.18	-0.10	-0.06	-0.14	0.20	-0.26	-0.51
c299	-0.09	0.24	-0.18	0.20	0.21	0.26	-0.02	-0.15	0.05	0.23	0.42	-0.12	0.17
c369	**0.28**	0.13	0.02	0.02	-0.02	-0.04	0.01	0.04	0.10	-0.12	-0.19	0.02	-0.12
c370	**0.26**	-0.07	-0.19	0.16	-0.01	-0.09	-0.03	0.03	-0.07	0.02	-0.05	-0.08	0.00
c371	-0.11	-0.03	-0.27	0.25	-0.16	0.22	0.30	0.33	0.18	-0.03	-0.12	0.12	0.17
c372	-0.13	0.37	-0.10	0.03	0.19	0.04	-0.08	0.02	0.22	0.12	-0.05	0.10	-0.07
c433	0.17	0.21	0.02	0.20	-0.28	-0.03	-0.12	0.14	-0.24	0.26	0.09	-0.07	-0.18
c434	0.13	0.12	-0.02	0.26	-0.31	-0.17	-0.27	-0.02	-0.16	0.19	0.17	0.40	0.33
c441	**0.25**	0.20	0.10	-0.07	-0.03	0.14	0.12	0.12	0.02	-0.11	-0.07	0.00	-0.03
c442	**0.26**	0.11	-0.02	0.20	-0.04	-0.20	-0.10	0.02	0.08	-0.13	-0.14	0.09	0.01
c443	**0.18**	-0.26	-0.20	0.13	0.17	-0.08	0.10	0.09	-0.04	-0.03	0.04	-0.07	0.13
c444	**-0.21**	-0.09	-0.09	0.24	0.02	0.09	0.35	0.27	-0.10	-0.17	-0.14	0.10	0.20
c445	-0.17	0.36	0.03	0.05	0.18	-0.08	-0.02	-0.04	0.12	0.11	-0.17	0.12	-0.25
c446	0.07	0.19	-0.09	0.24	0.48	0.10	-0.02	-0.07	-0.01	-0.04	0.20	0.16	0.14
c505	0.17	0.20	0.14	-0.11	-0.09	0.31	0.19	0.23	-0.21	0.20	-0.04	-0.19	0.05
c506	**0.26**	0.21	0.04	0.05	-0.19	0.02	0.02	0.07	0.03	-0.02	-0.01	-0.04	0.12
c507	**0.26**	0.03	-0.08	-0.07	-0.07	-0.09	0.04	-0.11	0.43	-0.16	0.11	-0.07	0.19
c508	0.18	-0.25	-0.24	-0.16	0.04	-0.05	0.01	-0.09	0.29	0.12	0.19	-0.07	0.00
c509	0.02	-0.33	-0.25	-0.13	0.08	0.16	-0.19	0.19	-0.24	0.36	-0.04	0.22	-0.17
c510	**0.23**	0.09	0.13	0.06	0.00	0.24	-0.42	0.16	0.03	-0.24	-0.14	-0.15	-0.01
c511	-0.14	0.16	0.10	-0.03	-0.05	-0.36	0.56	-0.26	-0.24	0.12	0.04	0.09	-0.02

Each color function is typically very effective in separating one or two time treatment *time combinations from all others (Table 4-62). For example, Can1 is very effective in separating P1-Air, P1-CO_2, P2-Air and P2-CO_2 treatments at time 15 and 17 days from other time*treatment combinations. Can1 also gave good separation on P1-Air and P2-Air treatments at day 17, which means that they deteriorated earlier than CO_2 treated zucchini samples in terms of color changes. However, treatment groups did not give good separation from each other from day 0 to 10 using Can1 and Can2 only.

Another approach was tried by combining similar color blocks to see if we could obtain better separation between treatment groups by time. Color blocks from 441 to 446 were combined to form group A, and Colors from 505 to 508 were combined to form group B. Color blocks 370 and 371 were combined as group C. CDA was performed on these reduced color data. It can be seen the first two canonical variables would do a satisfactory job of describing the separation of treatments by time (Table 4-63 and Table 4-64). Can1 was sufficient to discriminate P2-Air sample at day 17 and P1-Air samples at day 15 when reduced color blocks are used. Can2 was capable of separating P1-Air, P2-Air and P1-CO_2 treatment groups at day 13 as well as P1-Air and P2-CO_2 at day 10. From day 0 to 10 , treatment groups can also be separated using Can2 variable (Table 4-64).

PCA of E-nose Data of Experiment II

Table 4-65 presents the means and variances for e-nose data of different treated samples. The first principal component explains 93% of the total variation in the data. The second principal component with a variance=0.51 explains about 4% of the total variability, and the first two together explain 97% of the variation in the e-nose data

Table 4-62. Class means on canonical variables of color data for experiment II

Treatment	Storage Time (Days)	Can1	Can2
P1-Air	0	-2.77	0.63
	3	-2.65	0.72
	6	-2.30	-0.19
	8	-2.07	-0.53
	10	-1.08	-0.55
	13	3.03	-3.46
	15	5.74	-3.67
	17	10.33	0.82
P1-CO_2	0	-2.29	1.63
	3	-2.52	1.72
	6	-1.66	0.64
	8	-2.60	-0.05
	10	-1.15	-0.07
	13	-1.28	-0.42
	15	0.79	-1.83
	17	5.37	-2.51
P2-Air	0	-2.08	0.46
	3	-2.66	0.24
	6	-2.21	1.00
	8	-2.11	-0.56
	10	-1.32	-0.01
	13	0.12	-1.17
	15	4.06	-0.95
	17	9.94	6.52
P2-CO_2	0	-1.72	1.67
	3	-1.89	1.22
	6	-0.91	0.00
	8	-1.89	0.37
	10	-1.36	-0.19
	13	-2.33	0.51
	15	0.27	-0.98
	17	3.22	-1.01

12 replications of samples per each storage time

Table 4-63. Raw canonical coefficients for combined color blocks of experiment II

Reduced Colors	Can1	Can2	Can3
A	0.03	0.09	0.24
B	0.72	-0.52	0.65
C	1.72	2.56	-0.04

Table 4-64. Class means on canonical variables of combined color data for experiment II

Treatments	Storage Time (Days)	Can1	Can2	Can3
P1-Air	0	-1.56	-0.92	0.05
	3	-1.52	-0.79	0.38
	6	-1.48	-0.66	0.70
	8	-1.48	-0.66	0.70
	10	-0.42	0.82	0.26
	13	1.08	1.72	-0.33
	15	2.21	1.36	0.39
	17	5.82	-2.27	-0.76
P1-CO_2	0	-1.58	-1.01	-0.16
	3	-1.61	-1.11	-0.41
	6	-0.88	0.03	-0.17
	8	-1.58	-1.02	-0.18
	10	-0.77	0.20	-0.14
	13	-0.19	1.06	-0.21
	15	-0.43	0.79	0.21
	17	2.26	0.64	-0.26
P2-Air	0	-0.60	0.48	-0.07
	3	-1.48	-0.66	0.71
	6	-1.59	-1.04	-0.24
	8	-1.51	-0.76	0.46
	10	-0.63	0.43	-0.08
	13	-0.26	1.00	-0.01
	15	2.09	1.46	0.55
	17	10.31	-1.02	0.58
P2-CO_2	0	-0.87	0.06	-0.11
	3	-0.84	0.11	-0.08
	6	-0.69	0.32	-0.18
	8	-0.86	0.14	0.12
	10	-0.69	0.34	-0.11
	13	-1.63	-1.16	-0.53
	15	0.00	0.82	-0.30
	17	1.36	1.29	-0.79

*12 replications of samples per each storage time

Table 4-65. Mean and standard deviation of sensor readings used for PCA analysis for experiment II.

Sensors	Mean (%)[1]	Std Dev [1]	Minimum	Maximum
T_301	3.37	0.31	1.98	3.92
T_298	17.41	1.12	12.7	19.45
T_297	15.79	1.00	11.56	17.6
T_283	8.63	0.50	6.52	9.65
T_278	4.85	0.31	3.31	5.37
T_264	15.56	0.91	12.14	18.26
T_263	11.10	0.85	7.57	12.79
T_262	5.75	0.47	3.63	6.54
T_261	6.57	0.43	4.67	7.36
T_260	7.53	0.49	5.35	8.38
T_259	5.40	0.30	4.08	5.97
T_258	7.81	0.43	5.96	9.36

[1] 6 replications used for mean and st. dev. calculations for e-nose measurements for PCA

Table 4-66. Eigenvalues and percent total variability of the correlation matrix obtained by PCA for e-nose data set of experiment II.

Principal components	Eigenvalue	Proportion	Cumulative
1	**11.16**	**0.93**	**0.93**
2	**0.51**	**0.04**	**0.97**
3	0.16	0.01	0.98
4	0.07	0.00	0.99
5	0.04	0.00	0.99
6	0.01	0.00	0.99
7	0.01	0.00	0.99
8	0.00	0.00	0.99
9	0.00	0.00	0.99
10	0.00	0.00	0.99
11	0.00	0.00	0.99
12	0.00	0.00	1.00

(Table 4-66). Examination of second eigenvector (Prin 2) gave high eigenvalues for T_258 and T_264 sensors (Table 4-67). As a result, instead of using 12 sensors, odor can be measured by using 2 sensors.

CDA of E-nose Data of Experiment II

Results (Appendix E) indicated that the first two variables can explain more than 83% of total variance. The coefficients of canonical variables (Can1 and Can2) are shown in Table 4-68.

Attempting to use sensor discrimination among treatments by time. It is also observed that 2 functions separate treatments by time (Table 4-69). For example, Can1 is very effective in separating P1-Air and P2-Air from P1 and P2-CO_2 treatments at time 15 and 17days from other time*treatment combinations. However, treatment groups could not be separated from each other from day 3 to day 6 by Can1 and Can2. Twelve sensors were reduced to 3 sensors for better discrimination between treatments. It was observed that the first two variables explain more than 97% of the total variance (Appendix E and Table 4-70). Can1 was sufficient to discriminate treatments at all sampling days better when reduced sensors were used. Can2 was capable of separating P1-Air and P2-Air treatment groups at day 6 as well as P1-Air, P2-Air and P2-CO_2 at day 8. From day 0 to day 6 , treatment groups can be separated using Can2 variable. When evaluating the T-258, T_301 and T_261 separation by time, Can1 was very effective to separate treatment groups. They all showed similar separation trend.

Canonical Correlation for Experiment II

Table 4-71 shows the relationship between color and sensory data was linear (r=0.99). It means that when increase in yellow (browning) color formation over time

Table 4-67. Eigenvectors (PCA coefficients) from e-nose data set of zucchini experiment II

Sensors	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6
T_301	**0.29**	-0.03	-0.25	-0.37	0.13	0.00
T_298	**0.29**	0.10	-0.51	-0.09	-0.06	0.09
T_297	**0.29**	0.12	-0.51	-0.02	0.05	0.04
T_283	**0.30**	-0.02	-0.14	0.32	-0.17	-0.54
T_278	**0.30**	0.01	0.19	-0.20	0.51	-0.54
T_264	**0.29**	**-0.30**	0.12	0.68	0.03	-0.02
T_263	**0.29**	-0.28	-0.07	0.24	0.28	0.51
T_262	**0.29**	-0.18	0.29	-0.28	0.23	0.29
T_261	**0.29**	-0.14	0.38	-0.18	-0.17	0.02
T_260	**0.30**	0.03	0.23	-0.14	-0.25	-0.10
T_259	**0.30**	-0.01	0.07	-0.12	-0.66	0.11
T_258	**0.23**	**0.87**	0.25	0.24	0.12	0.20

Table 4-68. Raw canonical coefficients for e-nose sensors of experiment II

Sensors	Can1	Can2
T_301	-12.77	-10.33
T_298	-3.14	0.48
T_297	5.21	2.24
T_283	-3.42	2.85
T_278	-11.46	-16.51
T_264	2.15	-7.00
T_263	8.19	25.17
T_262	-5.80	-33.10
T_261	-14.25	1.21
T_260	-6.08	9.17
T_259	9.21	7.55
T_258	13.83	-7.33

Table 4-69. Class means on canonical variables of e-nose data for experiment II

Treatments	Storage Time (Days)	Can1	Can2
P1-Air	0	-0.91	6.74
	3	-2.72	4.87
	6	-3.52	5.85
	8	-3.16	0.93
	10	0.25	-2.89
	13	3.07	-3.62
	15	13.25	8.21
	17	8.16	-7.29
P1-CO_2	0	-1.43	5.96
	3	-4.03	3.68
	6	-4.48	4.02
	8	-4.87	0.06
	10	-2.23	-1.78
	13	0.51	-3.12
	15	8.78	7.47
	17	3.29	-6.37
P2-Air	0	-0.60	2.83
	3	-3.78	1.12
	6	-5.37	1.38
	8	-5.64	-1.26
	10	-1.98	-4.17
	13	-0.31	-4.25
	15	10.76	3.39
	17	6.01	-9.10
P2-CO_2	0	-1.68	3.17
	3	-4.47	1.08
	6	-4.63	-0.13
	8	-5.60	-1.93
	10	-2.66	-5.05
	13	-2.19	-4.79
	15	7.82	3.37
	17	4.35	-8.41

*6 replications of samples per each storage time

Table 4-70. Class means on canonical variables of reduced sensor data for experiment II

Treatment	Storage Time (Days)	Can1	Can2
P1-Air	0	3.40	-0.26
	3	3.99	-0.61
	6	4.67	-0.55
	8	3.12	1.54
	10	-1.58	0.55
	13	-3.69	0.56
	15	-6.41	-1.03
	17	-8.44	0.49
P1-CO_2	0	3.34	-1.36
	3	4.28	-1.17
	6	4.10	-0.88
	8	3.52	-0.57
	10	0.58	1.09
	13	-0.77	0.47
	15	-3.68	-1.37
	17	-4.93	0.52
P2-Air	0	1.69	0.15
	3	3.08	-0.45
	6	4.54	-0.06
	8	3.20	0.02
	10	-0.10	0.99
	13	-1.03	0.93
	15	-6.41	-0.51
	17	-8.24	0.12
P2-CO_2	0	2.26	-0.04
	3	3.65	-0.35
	6	3.42	0.46
	8	3.10	1.39
	10	-0.18	1.26
	13	-0.03	0.66
	15	-4.28	-1.34
	17	-6.15	-0.68

was rated by panelist, increase in c442 color, which is brilliant yellow green, was also reported by machine vision system.

Only odor related sensory attributes were correlated with sensor readings from e-nose for a possible better correlation. Canonical correlation was a significant (Table 4-71). There was a high correlation among the T_263, T_261 and T_258 sensors and off odor. It was also observed that very good correlation between fresh zucchini aroma values given by panelist and T_264 and T_262 sensors readings from e-nose (Appendix E). Analysis was also performed by reducing sensors amounts. Similar results were obtained. Results in Appendix E shows high correlation between off-odor and T_258 . Similarly, high linear relationship was observed between fresh zucchini aroma and T_264. We can conclude that there is no need to use 12 sensors.

High correlation was observed between microbial count and sensors T_297, T_283, T_262, T_261, which means increase in microbial count was also "smelled " by those sensors due to off-odor formation (Table 4-71 and Appendix E).

Sensors were reduced from 12 to 2 using PCA. From canonical correlation analysis, one significant canonical correlation was obtained (Table 4-71). There was positive high correlation between microbial count and T_258, and a negative correlation between microbial count and T_264 (Appendix E).

When sensory attributes hardness and crispness for texture analysis were used, there is a strong relationship between texture measurements using small and big blades and these attributes (Table 4-71 and Appendix E). There was a significant canonical correlation between canonical variables. Both blades had significant positive correlation with crispness, but they gave negative correlation with hardness to softness. Surface

Table 4-71. The canonical correlation between objective readings and sensory evaluations in experiment II.

Objective readings	Sensory evaluations							
	Color (whiteness-yellowness)		Odor (Fresh zucchini aroma and off-odor)		Texture (Hardness-Crispness)		Microbial growth	
	r	P- value	r	P-value	r	P-value	r	P-value
Machine vision	0.99	0.01	—	—	—	—	—	—
E-nose (all)	—	—	0.95	0.01	—	—	0.93	0.01
E-nose (reduced)	—	—	0.91	0.01	—	—	0.86	0.01
Microbial count	—	—	0.89	0.01	—	—	—	—
Instron	—	—	—	—	0.88	0.01	—	—

breakdown, dry-wet, hardness and crispness were used for correlation with instron to better express textural changes. There was a significant positive correlation between big blade and dry-wet sensory attributes, and a negative correlation with hardness. Small blade showed significant correlation with crispness.

Canonical correlation of microbial count and all sensory attributes was significant (Table 4-71).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study suggested that the quality attributes of modified atmosphere stored sliced zuccchini squash can be measured objectively and rapidly using electronic nose, machine vision, and Instron, giving results similar to those obtained from sensory panelists. This study also indicated that sensory panel results and microbial counts can be correlated with the electronic nose sensor readings and machine vision evaluations.

The results obtained from this study showed that using controlled atmosphere for the initial study, and modified atmosphere for the second experiment significantly reduced microbial growth, off-odor, off flavor, surface breakdown, degree of transparency, discoloration and yellowness during storage. These experiments also preserved the textural properties while maintaining hardness, crispness, normal surface moisture, fresh zucchini aroma and zucchini flavor. However, using modified atmosphere for the first experiment did not provide similar results. The reason for that could be the difference in the variety of zucchini squash used for experiment I.

Using two different plastic bags for modified atmosphere packaging study did not significantly affect the quality of samples. Also, the bags used for modified atmosphere study did not provide the right atmosphere throughout the whole storage time.

Average L*a*b* values and % color changes showed that the best color preservation was with 15%CO_2 treatment. Correct classification rates and crossvalidation rates for color data and electronic nose sensor readings were high for all treatments.

The correlations among different color blocks, electronic sensor readings, textural parameters, and microbial loads with different sensory attributes were high. For this study, comparisons of trends between experiments could not be performed because different varieties of zucchini squash were used as raw material, and responded differently to treatments.

This project suggests that the use of objective methods, correlated to sensory results, can save time, cost, and increase reliability of food quality evaluation. Further work is needed to develop and train neural networks, using objective readings as inputs, and shelf-life as output. When properly trained, neural networks can be used to predict the shelf life of modified atmosphere stored sliced zucchini squash.

APPENDIX A
CALCULATION OF RESPIRATION RATE AND FLOW RATE

Calculation of Respiration rate

Average of three readings = 1.5%CO_2.

For a static system:

RR= %CO_2 x V /(M x t x100)   (1)

where %CO_2 (in the headspace readings from GC) was the concentration of carbon dioxide that accumulated in the jar during the measurement period, V (ml) was the volume of free space of the jar (assume the sample occupies 1ml / g fresh weight), M(kg) was the mass of the product in the jar and t(hr) was the time during which CO_2 accumulated in the jar; RR (ml CO_2 /kg-hr) was the respiration rate.

Sample weight= 0.354kg

Volume of the container= 2210 ml

Void volume=volume of free space of jar= 1 ml = 1 g (assume the sample occupies 1ml/g fresh weight)

V = 2210- 354.42 ml

V = 1855.5 ml

time = 2 hr

%CO_2= 1.5

ml CO_2 /kg hr= 1.5 * 1855.5ml/ (0.354* 2*100)

RR =39.31 mlCO_2/kg hr

Calculation of Flow Rate:

Total flow rate (ml/min)= Respiration rate (ml CO_2/kg-hr) / (0.005 x 60 min/hr)

For 1 kg (0.005= % CO_2 / 100)

ml/min = ml CO_2 /kg hr/ 0.005 * 60 min/hr

Flow rate= 39.31 mlCO_2/kg hr/ (0.005* 60 min/hr) = 133.33 ml/min kg.

For a container holding 200g of product:

1/5= 200g⇒ 133.33/5 = ~26.66 ml/min/ per container

For 10 containers = 266.6 ml/min

Determination of flow rate of each gas composition:

X% O_2 + Y % CO_2 + 100 - (X+Y) % N_2

For the composition of 2% O_2+7%CO_2:

100 ml air* 2% O_2/ 20.8%O_2 = 9.6 % air

9.6% air +7 %CO_2 + X%N_2 =100

X%N_2= 100 - (9.6 %air + 7% CO_2)

N_2 = 83.4%

For air = 266 * 9.6 /100

= 25.53 ml air

For CO_2= 266* 7/100

=18.62 ml CO_2

For N_2= 266* 83.4/100

= 221.84 mlN_2

For the composition of 2% O_2+15%CO_2:

$$9.6\% \text{ air} + 15\%CO_2 + N_2\% = 100$$

$$N_2 = 24.6 - 100$$

$$N_2 = 75.4\ \%$$

For air: 266* 9.6/100

=25.53 ml air

For CO_2 :266*15/100

= 40 ml CO_2

For N_2:= 266*75.4/100

=251.08 ml N_2

APPENDIX B
SENSORY BALLOTS

Controlled Atmosphere Experiment

06/08/00

Name:________________ Panelist #:______________

SENSORY PANEL FOR ZUCCHINI SQUASH

Directions:

- You will be presented with sliced zucchini squash samples.
- Please rate smell color and texture of presented samples in an order
- Add any comments if possible.

COLOR

PEEL COLOR

YELLOWNESS:|____|
None High

GREENNESS: |____|
None High

FLESH COLOR

BROWNING: |____|
None High

DEGREE OF
DISCOLORATION:

|____|
None High

TEXTURE

HARDNESS: |____|
None High

CRISPNESS: |____|
None High

ODOR

OFF-ODOR: |____|
None High

ZUCCHINI |____|
AROMA: None High

Experiment I-II
05/11/01

Name:______________ Panelist #:______________

SENSORY PANEL FOR ZUCCHINI SQUASH

Directions:

- YOU WILL BE PRESENTED WITH SOME SLICED ZUCCHINI SQUASH SAMPLES.
- PLEASE EVALUATE SMELL, COLOR, SURFACE, TASTE, AND TEXTURE OF PRESENTED SAMPLES IN AN ORDER
- PLEASE RATE THE INTENSITY OF EACH ATTRIBUTES
- PLEASE USE CRACKER AND WATER BETWEEN SAMPLES

ODOR

OFF-ODOR

|____|

None High

FRESH ZUCCHINI AROMA

|____|

None High

COLOR:

WHITE YELLOW

|____|

DEGREE OF TRANSPARENCY

|____|

None High

SURFACE:

SURFACE BREAKDOWN

|____|

None High

DRY: WET

|____|

TEXTURE

HARD: SOFT

|____|

CRISPNESS:

|____|

None High

APPENDIX C
DESCRIPTIVE LIST OF 512 COLOR BLOCKS

Table C-1. Description of the 512-color block scheme used in the Color Analysis Software

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
0	16	16	16	0.89	0.00	0.00	black	267
1	16	16	48	1.57	4.65	-16.67	vivid blue	176
2	16	16	80	3.44	17.48	-38.15	vivid blue	176
3	16	16	112	6.85	32.79	-55.38	vivid blue	176
4	16	16	144	11.55	41.92	-69.33	vivid blue	176
5	16	16	176	16.27	50.21	-82.45	vivid blue	176
6	16	16	208	20.90	58.11	-95.08	vivid blue	176
7	16	16	240	25.46	65.74	-107.32	vivid blue	176
8	16	48	16	9.82	-18.21	12.23	very dark yellowish green	138
9	16	48	48	10.39	-13.11	-3.79	very dark bluish green	166
10	16	48	80	11.85	-1.00	-24.67	dark blue	183
11	16	48	112	14.19	12.71	-43.33	deep blue	179
12	16	48	144	17.20	25.59	-59.99	vivid blue	176
13	16	48	176	20.66	37.15	-75.16	vivid blue	176
14	16	48	208	24.40	47.56	-89.27	vivid blue	176
15	16	48	240	28.30	57.08	-102.59	vivid blue	176
16	16	80	16	23.26	-32.19	26.67	very deep yellowish green	133
17	16	80	48	23.52	-29.09	13.31	very dark yellowish green	138
18	16	80	80	24.19	-21.59	-6.13	dark bluish green	165
19	16	80	112	25.38	-10.67	-25.66	dark greenish blue	174
20	16	80	144	27.07	1.92	-44.05	deep blue	179
21	16	80	176	29.24	14.79	-61.15	vivid blue	176
22	16	80	208	31.81	27.22	-77.09	vivid blue	176
23	16	80	240	34.69	38.92	-92.04	vivid blue	176
24	16	112	16	35.90	-43.34	36.21	deep yellowish green	132
25	16	112	48	36.04	-41.51	27.00	deep yellowish green	132
26	16	112	80	36.44	-36.75	10.45	strong green	141
27	16	112	112	37.14	-29.00	-8.20	moderate bluish green	164
28	16	112	144	38.19	-18.92	-26.80	strong greenish blue	169
29	16	112	176	39.59	-7.39	-44.70	strong blue	178

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
30	16	112	208	41.34	4.78	-61.72	vivid blue	176
31	16	112	240	43.39	17.01	-77.88	vivid blue	176
32	16	144	16	47.95	-53.76	45.04	vivid yellowish green	129
33	16	144	48	48.05	-52.54	38.44	strong yellowish green	131
34	16	144	80	48.31	-49.28	24.82	strong yellowish green	131
35	16	144	112	48.78	-43.70	7.81	strong green	141
36	16	144	144	49.50	-35.95	-10.16	strong bluish green	160
37	16	144	176	50.47	-26.44	-28.05	strong greenish blue	169
38	16	144	208	51.70	-15.71	-45.47	strong blue	178
39	16	144	240	53.19	-4.27	-62.27	vivid blue	176
40	16	176	16	59.58	-63.72	53.46	vivid yellowish green	129
41	16	176	48	59.65	-62.84	48.52	vivid yellowish green	129
42	16	176	80	59.83	-60.46	37.38	vivid yellowish green	129
43	16	176	112	60.17	-56.28	22.27	brilliant green	140
44	16	176	144	60.69	-50.28	5.38	brilliant bluish green	159
45	16	176	176	61.40	-42.59	-12.03	brilliant bluish green	159
46	16	176	208	62.32	-33.51	-29.37	brilliant greenish blue	168
47	16	176	240	63.44	-23.39	-46.36	vivid greenish blue	167
48	16	208	16	70.86	-73.34	61.58	vivid yellowish green	129
49	16	208	48	70.91	-72.67	57.74	vivid yellowish green	129
50	16	208	80	71.05	-70.85	48.59	vivid yellowish green	129
51	16	208	112	71.31	-67.61	35.32	vivid yellowish green	129
52	16	208	144	71.70	-62.86	19.74	vivid green	139
53	16	208	176	72.25	-56.61	3.11	brilliant bluish green	159
54	16	208	208	72.96	-49.01	-13.83	brilliant bluish green	159
55	16	208	240	73.83	-40.26	-30.72	vivid greenish blue	167
56	16	240	16	81.85	-82.69	69.46	vivid yellowish green	129
57	16	240	48	81.89	-82.17	66.40	vivid yellowish green	129
58	16	240	80	82.00	-80.72	58.79	vivid yellowish green	129
59	16	240	112	82.21	-78.14	47.21	vivid yellowish green	129
60	16	240	144	82.52	-74.29	32.98	vivid green	139
61	16	240	176	82.95	-69.15	17.31	vivid green	139

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
62	16	240	208	83.52	-62.76	0.96	vivid bluish green	158
63	16	240	240	84.22	-55.25	-15.60	vivid bluish green	158
64	48	16	16	4.14	14.17	4.98	deep reddish brown	41
65	48	16	48	4.81	18.58	-11.55	very deep reddish purple	239
66	48	16	80	6.68	26.97	-32.75	vivid purplish blue	194
67	48	16	112	9.94	35.06	-50.18	vivid blue	176
68	48	16	144	13.83	43.05	-65.49	vivid blue	176
69	48	16	176	17.97	50.93	-79.57	vivid blue	176
70	48	16	208	22.23	58.61	-92.84	vivid blue	176
71	48	16	240	26.52	66.11	-105.53	vivid blue	176
72	48	48	16	12.37	-3.42	16.01	dark olive	108
73	48	48	48	12.84	0.00	0.00	black	267
74	48	48	80	14.08	7.70	-21.03	dark purplish blue	201
75	48	48	112	16.12	17.87	-40.12	deep blue	179
76	48	48	144	18.82	28.61	-57.28	vivid blue	176
77	48	48	176	22.00	38.98	-72.90	vivid blue	176
78	48	48	208	25.51	48.72	-87.39	vivid blue	176
79	48	48	240	29.23	57.86	-101.02	vivid blue	176
80	48	80	16	24.44	-22.80	28.09	dark olive green	126
81	48	80	48	24.68	-20.37	14.97	very dark yellowish green	138
82	48	80	80	25.32	-14.33	-4.37	dark bluish green	165
83	48	80	112	26.44	-5.16	-23.94	dark blue	183
84	48	80	144	28.06	5.88	-42.42	deep blue	179
85	48	80	176	30.14	17.57	-59.66	vivid blue	176
86	48	80	208	32.61	29.16	-75.74	vivid blue	176
87	48	80	240	35.41	40.29	-90.83	vivid blue	176
88	48	112	16	36.58	-37.47	37.02	deep yellowish green	132
89	48	112	48	36.72	-35.84	27.90	deep yellowish green	132
90	48	112	80	37.11	-31.58	11.44	moderate green	145
91	48	112	112	37.80	-24.56	-7.18	moderate bluish green	164
92	48	112	144	38.82	-15.28	-25.79	moderate greenish blue	173
93	48	112	176	40.19	-4.51	-43.72	strong blue	178
94	48	112	208	41.90	7.01	-60.79	vivid blue	176
95	48	112	240	43.92	18.73	-77.01	vivid blue	176

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
96	48	144	16	48.41	-49.76	45.58	strong yellowish green	131
97	48	144	48	48.50	-48.61	39.02	strong yellowish green	131
98	48	144	80	48.76	-45.55	25.45	strong yellowish green	131
99	48	144	112	49.23	-40.29	8.48	strong green	141
100	48	144	144	49.93	-32.94	-9.48	strong bluish green	160
101	48	144	176	50.89	-23.87	-27.38	strong greenish blue	169
102	48	144	208	52.11	-13.56	-44.81	strong blue	178
103	48	144	240	53.58	-2.49	-61.63	vivid blue	176
104	48	176	16	59.90	-60.80	53.85	vivid yellowish green	129
105	48	176	48	59.97	-59.96	48.92	vivid yellowish green	129
106	48	176	80	60.16	-57.67	37.82	vivid yellowish green	129
107	48	176	112	60.49	-53.65	22.73	brilliant green	140
108	48	176	144	61.01	-47.86	5.86	brilliant bluish green	159
109	48	176	176	61.71	-40.41	-11.54	brilliant bluish green	159
110	48	176	208	62.62	-31.59	-28.88	brilliant greenish blue	168
111	48	176	240	63.74	-21.72	-45.88	vivid greenish blue	167
112	48	208	16	71.10	-71.11	61.87	vivid yellowish green	129
113	48	208	48	71.15	-70.46	58.04	vivid yellowish green	129
114	48	208	80	71.30	-68.69	48.91	vivid yellowish green	129
115	48	208	112	71.55	-65.54	35.67	vivid yellowish green	129
116	48	208	144	71.95	-60.90	20.10	vivid green	139
117	48	208	176	72.49	-54.79	3.48	brilliant bluish green	159
118	48	208	208	73.19	-47.35	-13.47	brilliant bluish green	159
119	48	208	240	74.06	-38.77	-30.35	brilliant greenish blue	168
120	48	240	16	82.04	-80.93	69.69	vivid yellowish green	129
121	48	240	48	82.08	-80.41	66.63	vivid yellowish green	129
122	48	240	80	82.20	-79.00	59.04	vivid yellowish green	129
123	48	240	112	82.40	-76.46	47.47	vivid yellowish green	129
124	48	240	144	82.71	-72.68	33.26	vivid green	139
125	48	240	176	83.14	-67.62	17.59	vivid green	139
126	48	240	208	83.71	-61.34	1.25	vivid bluish green	158
127	48	240	240	84.40	-53.94	-15.30	vivid bluish green	158
128	80	16	16	12.30	30.24	17.34	deep brown	56
129	80	16	48	12.78	31.60	0.91	very dark red	17
130	80	16	80	14.02	34.96	-20.66	very deep reddish purple	239

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
131	80	16	112	16.06	40.08	-39.94	deep violet	208
132	80	16	144	18.77	46.33	-57.18	vivid purplish blue	194
133	80	16	176	21.96	53.13	-72.84	vivid purplish blue	194
134	80	16	208	25.48	60.17	-87.34	vivid blue	176
135	80	16	240	29.20	67.27	-100.99	vivid blue	176
136	80	48	16	17.72	15.72	23.52	dark brown	59
137	80	48	48	18.06	17.32	7.84	dark reddish brown	44
138	80	48	80	18.96	21.34	-13.16	very dark reddish purple	243
139	80	48	112	20.50	27.53	-32.88	deep violet	208
140	80	48	144	22.65	35.11	-50.89	vivid purplish blue	194
141	80	48	176	25.29	43.32	-67.39	vivid purplish blue	194
142	80	48	208	28.32	51.68	-82.66	vivid blue	176
143	80	48	240	31.63	59.94	-96.98	vivid blue	176
144	80	80	16	27.38	-5.51	31.53	moderate olive	107
145	80	80	48	27.59	-3.98	19.04	grayish olive	110
146	80	80	80	28.15	0.00	0.00	dark gray	266
147	80	80	112	29.14	6.42	-19.60	grayish purple blue	204
148	80	80	144	30.58	14.71	-38.29	deep blue	179
149	80	80	176	32.45	24.10	-55.82	vivid blue	176
150	80	80	208	34.71	33.94	-72.24	vivid blue	176
151	80	80	240	37.29	43.79	-87.67	vivid blue	176
152	80	112	16	38.39	-24.37	39.14	moderate olive green	125
153	80	112	48	38.52	-23.12	30.27	moderate olive green	125
154	80	112	80	38.88	-19.80	14.04	dark yellowish green	137
155	80	112	112	39.53	-14.21	-4.49	moderate bluish green	164
156	80	112	144	40.49	-6.59	-23.11	moderate blue	182
157	80	112	176	41.78	2.54	-41.12	strong blue	178
158	80	112	208	43.40	12.61	-58.32	vivid blue	176
159	80	112	240	45.32	23.13	-74.68	vivid blue	176
160	80	144	16	49.63	-40.00	47.01	strong yellowish green	131
161	80	144	48	49.72	-39.02	40.56	strong yellowish green	131
162	80	144	80	49.97	-36.40	27.14	strong yellowish green	131
163	80	144	112	50.42	-31.86	10.26	moderate green	145
164	80	144	144	51.10	-25.42	-7.66	moderate bluish green	164
165	80	144	176	52.02	-17.35	-25.56	strong greenish blue	169

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
166	80	144	208	53.20	-8.04	-43.03	strong blue	178
167	80	144	240	54.63	2.11	-59.90	vivid blue	176
168	80	176	16	60.79	-53.37	54.88	vivid yellowish green	129
169	80	176	48	60.86	-52.61	50.02	vivid yellowish green	129
170	80	176	80	61.04	-50.54	39.01	strong yellowish green	131
171	80	176	112	61.37	-46.90	23.99	strong yellowish green	131
172	80	176	144	61.87	-41.60	7.17	brilliant green	140
173	80	176	176	62.56	-34.76	-10.22	brilliant bluish green	159
174	80	176	208	63.45	-26.58	-27.56	brilliant greenish blue	168
175	80	176	240	64.54	-17.35	-44.58	brilliant blue	177
176	80	208	16	71.78	-65.29	62.66	vivid yellowish green	129
177	80	208	48	71.83	-64.68	58.87	vivid yellowish green	129
178	80	208	80	71.97	-63.03	49.79	vivid yellowish green	129
179	80	208	112	72.22	-60.08	36.60	vivid yellowish green	129
180	80	208	144	72.61	-55.73	21.07	brilliant green	140
181	80	208	176	73.14	-49.99	4.48	brilliant bluish green	159
182	80	208	208	73.84	-42.96	-12.46	brilliant bluish green	159
183	80	208	240	74.70	-34.81	-29.35	brilliant greenish blue	168
184	80	240	16	82.58	-76.24	70.32	vivid yellowish green	129
185	80	240	48	82.62	-75.75	67.28	vivid yellowish green	129
186	80	240	80	82.73	-74.41	59.72	vivid yellowish green	129
187	80	240	112	82.93	-71.99	48.19	vivid yellowish green	129
188	80	240	144	83.24	-68.38	34.01	vivid green	139
189	80	240	176	83.67	-63.55	18.37	vivid green	139
190	80	240	208	84.22	-57.53	2.04	brilliant bluish green	159
191	80	240	240	84.91	-50.43	-14.51	brilliant bluish green	159
192	112	16	16	21.09	40.94	29.38	deep reddish brown	41
193	112	16	48	21.37	41.72	13.58	deep red	13
194	112	16	80	22.13	43.76	-7.69	deep purplish red	256
195	112	16	112	23.44	47.16	-27.82	deep reddish purple	238
196	112	16	144	25.29	51.74	-46.32	vivid purple	216
197	112	16	176	27.64	57.20	-63.34	vivid violet	205
198	112	16	208	30.38	63.23	-79.12	vivid purplish blue	194
199	112	16	240	33.42	69.60	-93.88	vivid purplish blue	194
200	112	48	16	24.55	31.25	32.19	deep reddish brown	41

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
201	112	48	48	24.79	32.13	17.46	dark red	16
202	112	48	80	25.43	34.43	-2.99	dark purplish red	259
203	112	48	112	26.54	38.27	-23.05	deep reddish purple	238
204	112	48	144	28.15	43.45	-41.78	deep purple	219
205	112	48	176	30.22	49.60	-59.16	vivid violet	205
206	112	48	208	32.69	56.36	-75.34	vivid purplish blue	194
207	112	48	240	35.48	63.45	-90.51	vivid purplish blue	194
208	112	80	16	31.92	12.78	36.67	deep yellowish brown	75
209	112	80	48	32.09	13.72	25.15	moderate brown	58
210	112	80	80	32.55	16.22	6.67	dark red	16
211	112	80	112	33.37	20.45	-12.86	dark purple	224
212	112	80	144	34.58	26.25	-31.77	moderate violet	211
213	112	80	176	36.18	33.26	-49.66	vivid violet	205
214	112	80	208	38.15	41.05	-66.52	vivid purplish blue	194
215	112	80	240	40.43	49.27	-82.43	vivid purplish blue	194
216	112	112	16	41.41	-7.38	42.62	moderate olive	107
217	112	112	48	41.53	-6.49	34.18	moderate olive	107
218	112	112	80	41.85	-4.11	18.36	grayish olive	110
219	112	112	112	42.44	0.00	0.00	dark gray	266
220	112	112	144	43.31	5.78	-18.62	grayish purple blue	204
221	112	112	176	44.49	12.96	-36.73	strong purplish blue	196
222	112	112	208	45.97	21.19	-54.10	vivid purplish blue	194
223	112	112	240	47.74	30.08	-70.67	vivid blue	176
224	112	144	16	51.76	-25.67	49.48	strong yellow green	117
225	112	144	48	51.84	-24.90	43.22	strong yellow green	117
226	112	144	80	52.07	-22.82	30.06	moderate yellow green	120
227	112	144	112	52.50	-19.17	13.36	moderate yellowish green	136
228	112	144	144	53.14	-13.91	-4.49	moderate bluish green	164
229	112	144	176	54.01	-7.19	-22.40	moderate blue	182
230	112	144	208	55.12	0.74	-39.92	strong blue	178
231	112	144	240	56.48	9.57	-56.88	vivid blue	176
232	112	176	16	62.36	-41.63	56.71	strong yellow green	117
233	112	176	48	62.42	-40.98	51.94	strong yellow green	117
234	112	176	80	62.60	-39.23	41.10	strong yellowish green	131
235	112	176	112	62.92	-36.10	26.22	strong yellowish green	131

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
236	112	176	144	63.40	-31.53	9.48	light green	144
237	112	176	176	64.06	-25.56	-7.88	light bluish green	163
238	112	176	208	64.92	-18.33	-25.22	brilliant greenish blue	168
239	112	176	240	65.98	-10.07	-42.27	brilliant blue	177
240	112	208	16	72.99	-55.67	64.07	vivid yellowish green	129
241	112	208	48	73.04	-55.13	60.33	vivid yellowish green	129
242	112	208	80	73.17	-53.66	51.36	vivid yellowish green	129
243	112	208	112	73.42	-51.03	38.27	brilliant yellowish green	130
244	112	208	144	73.80	-47.12	22.81	brilliant green	140
245	112	208	176	74.32	-41.93	6.26	brilliant bluish green	159
246	112	208	208	74.99	-35.54	-10.65	brilliant bluish green	159
247	112	208	240	75.83	-28.07	-27.54	brilliant greenish blue	168
248	112	240	16	83.54	-68.29	71.45	vivid yellowish green	129
249	112	240	48	83.58	-67.84	68.43	vivid yellowish green	129
250	112	240	80	83.69	-66.60	60.94	vivid yellowish green	129
251	112	240	112	83.89	-64.38	49.48	vivid yellowish green	129
252	112	240	144	84.19	-61.05	35.37	vivid yellowish green	129
253	112	240	176	84.61	-56.58	19.77	brilliant green	140
254	112	240	208	85.15	-50.99	3.47	brilliant bluish green	159
255	112	240	240	85.83	-44.35	-13.07	brilliant bluish green	159
256	144	16	16	29.57	50.88	39.20	strong reddish brown	40
257	144	16	48	29.76	51.39	25.04	vivid red	11
258	144	16	80	30.26	52.77	4.84	deep purplish red	256
259	144	16	112	31.17	55.15	-15.38	deep purplish red	256
260	144	16	144	32.49	58.54	-34.51	vivid reddish purple	236
261	144	16	176	34.22	62.80	-52.41	vivid purple	216
262	144	16	208	36.34	67.77	-69.16	vivid violet	205
263	144	16	240	38.77	73.26	-84.91	vivid violet	205
264	144	48	16	31.96	44.09	40.19	strong reddish brown	40
265	144	48	48	32.13	44.64	27.32	deep red	13
266	144	48	80	32.59	46.12	7.90	deep purplish red	256
267	144	48	112	33.41	48.70	-12.09	deep purplish red	256
268	144	48	144	34.62	52.37	-31.22	vivid reddish purple	236
269	144	48	176	36.22	56.98	-49.26	vivid purple	216
270	144	48	208	38.18	62.33	-66.20	vivid violet	205

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
271	144	48	240	40.46	68.23	-82.16	Vivid violet	205
272	144	80	16	37.56	29.15	42.79	strong brown	55
273	144	80	48	37.69	29.76	32.45	dark reddish orange	38
274	144	80	80	38.06	31.39	14.82	moderate red	15
275	144	80	112	38.73	34.25	-4.47	moderate purplish red	258
276	144	80	144	39.72	38.33	-23.48	strong purple	218
277	144	80	176	41.05	43.48	-41.69	vivid purple	216
278	144	80	208	42.71	49.51	-58.98	vivid violet	205
279	144	80	240	44.67	56.15	-75.37	vivid violet	205
280	144	112	16	45.52	10.13	47.22	strong yellowish brown	74
281	144	112	48	45.62	10.75	39.35	strong yellowish brown	74
282	144	112	80	45.91	12.43	24.12	moderate brown	58
283	144	112	112	46.42	15.38	6.06	grayish red	19
284	144	112	144	47.18	19.64	-12.50	moderate purple	223
285	144	112	176	48.23	25.11	-30.70	light violet	210
286	144	112	208	49.54	31.58	-48.25	vivid violet	205
287	144	112	240	51.13	38.82	-65.07	vivid violet	205
288	144	144	16	54.79	-9.13	52.93	light olive	106
289	144	144	48	54.86	-8.54	46.95	light olive	106
290	144	144	80	55.08	-6.95	34.18	light olive	106
291	144	144	112	55.46	-4.13	17.73	light grayish olive	109
292	144	144	144	56.05	0.00	0.00	medium gray	265
293	144	144	176	56.86	5.38	-17.89	pale purplish blue	203
294	144	144	208	57.89	11.86	-35.47	brilliant purplish blue	195
295	144	144	240	59.15	19.24	-52.53	vivid purplish blue	194
296	144	176	16	64.66	-26.93	59.36	strong yellow green	117
297	144	176	48	64.72	-26.41	54.73	strong yellow green	117
298	144	176	80	64.88	-24.97	44.12	strong yellow green	117
299	144	176	112	65.18	-22.40	29.45	moderate yellow green	120
300	144	176	144	65.64	-18.61	12.84	moderate yellowish green	136
301	144	176	176	66.27	-13.60	-4.46	light bluish green	163
302	144	176	208	67.08	-7.46	-21.80	light blue	181
303	144	176	240	68.08	-0.33	-38.88	brilliant blue	177
304	144	208	16	74.79	-42.94	66.16	vivid yellow green	115
305	144	208	48	74.84	-42.48	62.49	vivid yellow green	115

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
306	144	208	80	74.97	-41.22	53.67	strong yellow green	117
307	144	208	112	75.20	-38.95	40.73	brilliant yellowish green	130
308	144	208	144	75.57	-35.57	25.39	brilliant yellowish green	130
309	144	208	176	76.07	-31.05	8.91	light green	144
310	144	208	208	76.72	-25.43	-7.98	very light bluish green	162
311	144	208	240	77.52	-18.80	-24.86	brilliant greenish blue	168
312	144	240	16	84.99	-57.35	73.13	vivid yellowish green	129
313	144	240	48	85.03	-56.95	70.16	vivid yellowish green	129
314	144	240	80	85.13	-55.85	62.76	vivid yellowish green	129
315	144	240	112	85.32	-53.87	51.42	vivid yellowish green	129
316	144	240	144	85.62	-50.90	37.40	brilliant yellowish green	130
317	144	240	176	86.03	-46.88	21.86	brilliant green	140
318	144	240	208	86.56	-41.83	5.60	brilliant bluish green	159
319	144	240	240	87.22	-35.81	-10.92	brilliant bluish green	159
320	176	16	16	37.78	60.36	47.10	vivid red	11
321	176	16	48	37.91	60.73	35.40	vivid red	11
322	176	16	80	38.28	61.72	16.67	vivid red	11
323	176	16	112	38.94	63.48	-3.19	vivid purplish red	254
324	176	16	144	39.92	66.05	-22.50	vivid reddish purple	236
325	176	16	176	41.24	69.40	-40.90	vivid purple	216
326	176	16	208	42.89	73.45	-58.31	vivid purple	216
327	176	16	240	44.84	78.08	-74.80	vivid violet	205
328	176	48	16	39.53	55.34	47.65	vivid red	11
329	176	48	48	39.65	55.73	36.81	vivid red	11
330	176	48	80	40.00	56.78	18.73	strong red	12
331	176	48	112	40.62	58.63	-0.85	vivid purplish red	254
332	176	48	144	41.55	61.34	-20.09	vivid reddish purple	236
333	176	48	176	42.80	64.87	-38.50	vivid purple	216
334	176	48	208	44.36	69.13	-55.99	vivid purple	216
335	176	48	240	46.22	73.99	-72.59	vivid violet	205
336	176	80	16	43.86	43.41	49.37	deep reddish orange	36
337	176	80	48	43.97	43.83	40.25	deep reddish orange	36
338	176	80	80	44.27	44.97	23.70	moderate red	15
339	176	80	112	44.81	47.00	4.85	moderate purplish red	258
340	176	80	144	45.61	49.96	-14.12	strong purplish red	255

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
341	176	80	176	46.71	53.83	-32.52	vivid purple	216
342	176	80	208	48.09	58.50	-50.14	vivid purple	216
343	176	80	240	49.75	63.84	-66.97	vivid violet	205
344	176	112	16	50.48	26.53	52.62	brownish orange	54
345	176	112	48	50.56	26.97	45.39	brownish orange	54
346	176	112	80	50.81	28.18	30.92	moderate reddish orange	37
347	176	112	112	51.24	30.33	13.28	moderate red	15
348	176	112	144	51.91	33.49	-5.13	moderate purplish red	258
349	176	112	176	52.81	37.64	-23.36	strong purple	218
350	176	112	208	53.96	42.70	-41.07	vivid purple	216
351	176	112	240	55.37	48.51	-58.13	vivid violet	205
352	176	144	16	58.62	7.75	57.23	deep yellow	85
353	176	144	48	58.69	8.19	51.58	dark orange yellow	72
354	176	144	80	58.89	9.40	39.30	dark orange yellow	72
355	176	144	112	59.24	11.56	23.21	light brown	57
356	176	144	144	59.77	14.75	5.67	light grayish red	18
357	176	144	176	60.50	18.98	-12.17	light purple	222
358	176	144	208	61.43	24.18	-29.79	brilliant purple	217
359	176	144	240	62.58	30.23	-46.96	brilliant violet	206
360	176	176	16	67.67	-10.81	62.78	strong greenish yellow	99
361	176	176	48	67.72	-10.39	58.33	moderate greenish yellow	102
362	176	176	80	67.88	-9.24	48.03	moderate greenish yellow	102
363	176	176	112	68.15	-7.18	33.64	grayish greenish yellow	105
364	176	176	144	68.58	-4.11	17.21	grayish yellow	90
365	176	176	176	69.17	0.00	0.00	light gray	264
366	176	176	208	69.93	5.10	-17.32	pale purplish blue	203
367	176	176	240	70.86	11.10	-34.43	light purplish blue	199
368	176	208	16	77.19	-28.18	68.91	brilliant yellow green	116
369	176	208	48	77.23	-27.80	65.35	brilliant yellow green	116
370	176	208	80	77.36	-26.74	56.72	brilliant yellow green	116
371	176	208	112	77.58	-24.84	43.99	brilliant yellow green	116
372	176	208	144	77.92	-21.98	28.81	light yellow green	119
373	176	208	176	78.40	-18.14	12.42	light yellow green	135
374	176	208	208	79.02	-13.32	-4.41	very light bluish green	162
375	176	208	240	79.79	-7.58	-21.29	very light blue	180

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
376	176	240	16	86.94	-44.13	75.38	vivid yellow green	115
377	176	240	48	86.98	-43.78	72.47	vivid yellow green	115
378	176	240	80	87.08	-42.83	65.20	vivid yellow green	115
379	176	240	112	87.26	-41.10	54.01	brilliant yellow green	116
380	176	240	144	87.55	-38.51	40.12	brilliant yellowish green	130
381	176	240	176	87.94	-34.99	24.68	very light yellowish green	134
382	176	240	208	88.45	-30.54	8.48	very light green	143
383	176	240	240	89.09	-25.19	-8.01	very light bluish green	162
384	208	16	16	45.76	69.51	54.53	vivid red	11
385	208	16	48	45.86	69.79	44.87	vivid red	11
386	208	16	80	46.14	70.54	27.76	vivid red	11
387	208	16	112	46.65	71.90	8.55	vivid purplish red	254
388	208	16	144	47.41	73.91	-10.66	vivid purplish red	254
389	208	16	176	48.44	76.59	-29.26	vivid reddish purple	236
390	208	16	208	49.75	79.90	-47.07	vivid purple	216
391	208	16	240	51.33	83.78	-64.08	vivid purple	216
392	208	48	16	47.10	65.65	54.91	vivid reddish orange	34
393	208	48	48	47.20	65.93	45.79	vivid red	11
394	208	48	80	47.46	66.72	29.19	vivid red	11
395	208	48	112	47.95	68.12	10.26	vivid purplish red	254
396	208	48	144	48.68	70.21	-8.84	vivid purplish red	254
397	208	48	176	49.68	72.99	-27.40	vivid reddish purple	236
398	208	48	208	50.94	76.42	-45.24	vivid purple	216
399	208	48	240	52.47	80.44	-62.29	vivid purple	216
400	208	80	16	50.53	56.02	56.10	vivid reddish orange	34
401	208	80	48	50.62	56.33	48.15	vivid reddish orange	34
402	208	80	80	50.86	57.17	32.79	vivid red	11
403	208	80	112	51.30	58.68	14.56	vivid red	11
404	208	80	144	51.96	60.92	-4.20	vivid purplish red	254
405	208	80	176	52.87	63.90	-22.66	vivid reddish purple	236
406	208	80	208	54.02	67.60	-40.50	vivid purple	216
407	208	80	240	55.42	71.92	-57.66	vivid purple	216
408	208	112	16	56.03	41.41	58.51	strong reddish orange	35
409	208	112	48	56.11	41.74	51.95	strong reddish orange	35
410	208	112	80	56.32	42.64	38.35	strong reddish orange	35

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
411	208	112	112	56.69	44.25	21.26	deep pink	3
412	208	112	144	57.26	46.65	3.10	deep purplish pink	248
413	208	112	176	58.04	49.86	-15.10	deep purplish pink	248
414	208	112	208	59.04	53.83	-32.90	vivid purple	216
415	208	112	240	60.26	58.51	-50.15	vivid purple	216
416	208	144	16	63.14	23.92	62.17	strong orange	50
417	208	144	48	63.20	24.26	56.89	strong orange	50
418	208	144	80	63.37	25.19	45.20	moderate orange	53
419	208	144	112	63.68	26.85	29.56	moderate reddish orange	37
420	208	144	144	64.15	29.34	12.27	deep pink	3
421	208	144	176	64.81	32.68	-5.46	dark purplish pink	251
422	208	144	208	65.65	36.84	-23.08	brilliant purple	217
423	208	144	240	66.68	41.76	-40.34	vivid purple	216
424	208	176	16	71.32	5.55	66.86	strong yellow	84
425	208	176	48	71.37	5.89	62.62	strong yellow	84
426	208	176	80	71.51	6.80	52.70	strong yellow	84
427	208	176	112	71.76	8.45	38.66	moderate orange yellow	71
428	208	176	144	72.16	10.92	22.46	moderate yellowish pink	29
429	208	176	176	72.70	14.26	5.39	moderate pink	5
430	208	176	208	73.40	18.44	-11.88	light purple	222
431	208	176	240	74.26	23.43	-29.01	light purple	222
432	208	208	16	80.16	-12.44	72.28	strong greenish yellow	99
433	208	208	48	80.20	-12.12	68.84	strong greenish yellow	99
434	208	208	80	80.32	-11.24	60.46	strong greenish yellow	99
435	208	208	112	80.53	-9.66	48.00	moderate greenish yellow	102
436	208	208	144	80.86	-7.29	33.02	grayish greenish yellow	105
437	208	208	176	81.30	-4.07	16.77	grayish yellow	90
438	208	208	208	81.89	0.00	0.00	light gray	264
439	208	208	240	82.61	4.89	-16.85	very pale purplish blue	202
440	208	240	16	89.40	-29.44	78.19	vivid yellow green	115
441	208	240	48	89.43	-29.14	75.36	brilliant yellow green	116
442	208	240	80	89.53	-28.33	68.25	brilliant yellow green	116
443	208	240	112	89.71	-26.85	57.25	brilliant yellow green	116
444	208	240	144	89.98	-24.62	43.53	light yellow green	119
445	208	240	176	90.35	-21.59	28.21	light yellow green	119

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
446	208	240	208	90.84	-17.73	12.09	very light yellowish green	134
447	208	240	240	91.45	-13.07	-4.36	very light bluish green	162
448	240	16	16	53.55	78.40	61.70	vivid reddish orange	34
449	240	16	48	53.63	78.62	53.64	vivid red	11
450	240	16	80	53.85	79.22	38.14	vivid red	11
451	240	16	112	54.25	80.29	19.78	vivid red	11
452	240	16	144	54.86	81.91	0.88	vivid purplish red	254
453	240	16	176	55.69	84.09	-17.72	vivid purplish red	254
454	240	16	208	56.75	86.83	-35.74	vivid reddish purple	236
455	240	16	240	58.05	90.10	-53.08	vivid purple	216
456	240	48	16	54.61	75.32	61.98	vivid reddish orange	34
457	240	48	48	54.69	75.55	54.26	vivid red	11
458	240	48	80	54.90	76.16	39.16	vivid red	11
459	240	48	112	55.29	77.27	21.05	vivid red	11
460	240	48	144	55.88	78.93	2.28	vivid purplish red	254
461	240	48	176	56.69	81.17	-16.26	vivid purplish red	254
462	240	48	208	57.73	83.98	-34.26	vivid reddish purple	236
463	240	48	240	58.99	87.33	-51.62	vivid purple	216
464	240	80	16	57.39	67.44	62.85	vivid reddish orange	34
465	240	80	48	57.47	67.67	55.93	vivid reddish orange	34
466	240	80	80	57.67	68.33	41.81	vivid red	11
467	240	80	112	58.03	69.50	24.34	vivid red	11
468	240	80	144	58.57	71.25	5.92	vivid purplish red	254
469	240	80	176	59.33	73.62	-12.46	vivid purplish red	254
470	240	80	208	60.29	76.60	-30.41	vivid reddish purple	236
471	240	80	240	61.48	80.15	-47.79	vivid purple	216
472	240	112	16	62.00	54.89	64.66	vivid reddish orange	34
473	240	112	48	62.07	55.14	58.76	vivid reddish orange	34
474	240	112	80	62.24	55.83	46.09	vivid reddish orange	34
475	240	112	112	62.56	57.08	29.66	deep yellowish pink	27
476	240	112	144	63.05	58.95	11.84	deep pink	3
477	240	112	176	63.72	61.49	-6.22	deep purplish pink	248
478	240	112	208	64.59	64.67	-24.05	vivid reddish purple	236
479	240	112	240	65.65	68.48	-41.43	vivid purple	216
480	240	144	16	68.17	39.01	67.56	strong orange	50

Table C-1, continued

Color Block #	RGB color system			L*a*b* color system			NBS Name	NBS #
	R	G	B	L	a	b		
481	240	144	48	68.23	39.28	62.68	strong orange	50
482	240	144	80	68.38	40.00	51.63	vivid yellowish pink	25
483	240	144	112	68.66	41.31	36.53	vivid yellowish pink	25
484	240	144	144	69.08	43.27	19.57	strong pink	2
485	240	144	176	69.66	45.93	2.00	strong purplish pink	247
486	240	144	208	70.41	49.28	-15.58	strong purplish pink	247
487	240	144	240	71.33	53.31	-32.89	vivid purple	216
488	240	176	16	75.52	21.45	71.47	strong orange yellow	68
489	240	176	48	75.56	21.72	67.47	strong orange yellow	68
490	240	176	80	75.69	22.45	57.99	strong orange	50
491	240	176	112	75.93	23.77	44.36	moderate orange	53
492	240	176	144	76.28	25.77	28.46	strong yellowish pink	26
493	240	176	176	76.78	28.48	11.56	strong pink	2
494	240	176	208	77.42	31.92	-5.64	light purplish pink	249
495	240	176	240	78.21	36.05	-22.76	brilliant purple	217
496	240	208	16	83.67	3.50	76.20	vivid yellow	82
497	240	208	48	83.71	3.76	72.90	brilliant yellow	83
498	240	208	80	83.81	4.48	64.81	brilliant yellow	83
499	240	208	112	84.01	5.79	52.66	light yellow	86
500	240	208	144	84.31	7.75	37.93	light orange yellow	70
501	240	208	176	84.73	10.44	21.85	light yellowish pink	28
502	240	208	208	85.28	13.85	5.18	light pink	4
503	240	208	240	85.95	17.99	-11.63	very light purple	221
504	240	240	16	92.34	-14.02	81.52	vivid greenish yellow	97
505	240	240	48	92.37	-13.77	78.78	brilliant greenish yellow	98
506	240	240	80	92.47	-13.08	71.86	brilliant greenish yellow	98
507	240	240	112	92.63	-11.83	61.09	brilliant greenish yellow	98
508	240	240	144	92.89	-9.93	47.57	light greenish yellow	101
509	240	240	176	93.24	-7.34	32.41	pale greenish yellow	104
510	240	240	208	93.71	-4.03	16.39	yellow white	92
511	240	240	240	94.29	0.00	0.00	white	263

APPENDIX D
CANONICAL DISCRIMINATION ANALYSIS

Table D-1 Canonical correlations of color blocks their squares and their approximate standard errors of controlled atmosphere experiment

Canonical Variables	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.89**	-	0.01	0.80
2	**0.89**	-	0.01	0.79
3	**0.86**	0.83	0.01	0.73
4	0.80	-	0.02	0.64
5	0.80	-	0.02	0.63
6	0.74	0.71	0.02	0.55
7	0.68	0.62	0.02	0.46
8	0.62	0.53	0.03	0.39
9	0.60	-	0.03	0.36
10	0.59	-	0.03	0.35
11	0.56	0.50	0.03	0.31
12	0.53	0.46	0.03	0.28
13	0.51	-	0.03	0.26
14	0.48	0.44	0.04	0.23
15	0.43	0.35	0.04	0.19
16	0.41	0.33	0.04	0.16
17	0.37	-	0.04	0.14
18	0.35	-	0.04	0.12
19	0.31	-	0.04	0.10
20	0.29	-	0.04	0.09
21	0.26	-	0.04	0.07
22	0.25	-	0.04	0.06
23	0.23	-	0.04	0.05
24	0.21	-	0.04	0.04
25	0.19	-	0.04	0.04

Table D-2. The eigenvalues, which are the estimated variances of respective canonical variables, obtained by CDA for color data of controlled atmosphere experiment

Canonical Variables	Eigenvalue	Difference	Proportion	Cumulative
1	**3.96**	**0.20**	**0.19**	**0.19**
2	**3.76**	**1.02**	**0.18**	**0.38**
3	**2.74**	**0.94**	**0.13**	**0.51**
4	1.79	0.07	0.09	0.60
5	1.72	0.49	0.08	0.68
6	1.23	0.37	0.06	0.74
7	0.86	0.23	0.04	0.78
8	0.63	0.07	0.03	0.81
9	0.56	0.03	0.03	0.84
10	0.53	0.07	0.03	0.86
11	0.46	0.06	0.02	0.89
12	0.39	0.04	0.02	0.91
13	0.36	0.05	0.02	0.92
14	0.31	0.07	0.01	0.94
15	0.23	0.04	0.01	0.95
16	0.20	0.03	0.01	0.96
17	0.16	0.02	0.01	0.97
18	0.14	0.03	0.01	0.97
19	0.11	0.01	0.01	0.98
20	0.09	0.02	0.00	0.98
21	0.07	0.01	0.00	0.99
22	0.07	0.01	0.00	0.99
23	0.05	0.01	0.00	0.99
24	0.05	0.01	0.00	0.99
25	0.04	0.01	0.00	1.00

Table D-3. Results of statistical tests to see how many canonical correlations are significantly different from zero for color data of controlled atmosphere experiment

Canonical Correlations	Likelihood Ratio	Approximate		
		F Value	Num DF	Pr > F
1	0.00	5.46	1170	0.0001
2	0.00	4.87	1102	0.0001
3	0.00	4.27	1036	0.0001
4	0.00	3.76	972	0.0001
5	0.00	3.39	910	0.0001
6	0.00	2.99	850	0.0001
7	0.01	2.68	792	0.0001
8	0.02	2.46	736	0.0001
9	0.03	2.3	682	0.0001
10	0.05	2.15	630	0.0001
11	0.08	1.98	580	0.0001
12	0.12	1.82	532	0.0001
13	0.16	1.67	486	0.0001
14	0.22	1.51	442	0.0001
15	0.29	1.36	400	0.0001
16	0.36	1.25	360	0.0014
17	0.43	1.14	322	0.0475
18	0.50	1.05	286	0.2800
19	0.58	0.96	252	0.6700
20	0.64	0.89	220	0.8700
21	0.70	0.82	190	0.9600
22	0.75	0.76	162	0.9800
23	0.80	0.70	136	0.9900
24	0.84	0.64	112	0.9900
25	0.88	0.58	90	0.9900
26	0.92	0.50	70	0.9900
27	0.95	0.39	52	1.0000
28	0.97	0.33	36	0.9900
29	0.98	0.29	22	0.9900
30	0.99	0.17	10	0.9900

Table D-4. Canonical correlations of reduced color blocks and their squares and their approximate standard errors of controlled atmosphere experiment

Canonical Variable	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.71	0.68	0.02	0.51
2	0.52	0.47	0.03	0.27
3	0.36	0.28	0.03	0.13

Table D-5. The eigenvalues obtained by CDA for reduced color data set of controlled atmosphere experiment

Canonical Variable	Eigenvalue	Difference	Proportion	Cumulative
1	1.04	0.65	0.65	**0.65**
2	0.38	0.22	0.24	**0.90**
3	0.16	-	0.09	1.00

Table D-6. Results of statistical tests to see how many canonical correlations are significantly different from zero for reduced color data of controlled atmosphere experiment

Canonical Correlations	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.31	5.44	117	1313	**0.0001**
2	0.63	3.05	76	878	**0.0001**
3	0.87	1.84	37	440	0.0024

Table D-7. Canonical correlations of e-nose data, their squares and their approximate standard errors of controlled atmosphere experiment

Canonical Variable	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.96	0.95	0.00	0.93
2	0.95	0.94	0.01	0.90
3	0.93	0.91	0.01	0.86
4	0.87	0.84	0.02	0.75
5	0.78	0.74	0.02	0.62
6	0.74	0.69	0.03	0.55
7	0.66	0.60	0.04	0.44
8	0.53	.	0.05	0.29
9	0.52	.	0.05	0.27
10	0.44	0.33	0.05	0.19
11	0.36	0.23	0.06	0.13
12	0.27	0.11	0.06	0.07

Table D-8. The eigenvalues, which are the estimated variances of respective canonical variables obtained by CDA for e-nose data set of controlled atmosphere experiment

Canonical Variable	Eigenvalue	Difference	Proportion	Cumulative
1	12.42	3.67	0.35	0.35
2	8.75	2.57	0.25	0.60
3	6.17	3.14	0.18	0.78
4	3.03	1.43	0.09	0.86
5	1.60	0.40	0.05	0.91
6	1.20	0.41	0.03	0.94
7	0.79	0.39	0.02	0.96
8	0.40	0.03	0.01	0.98
9	0.37	0.14	0.01	0.99
10	0.24	0.09	0.01	0.99
11	0.15	0.07	0.00	1.00
12	0.08	-	0.00	1.00

Table D-9. Results of statistical tests to see how many canonical correlations are significantly different from zero for e-nose data of controlled atmosphere experiment

Canonical Correlations	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.00	8.30	468	2213.60	0.0001
2	0.00	6.61	418	2046.20	0.0001
3	0.00	5.14	370	1875.70	0.0001
4	0.01	3.84	324	1702.10	0.0001
5	0.03	2.97	280	1525.30	0.0001
6	0.09	2.42	238	1345.40	0.0001
7	0.19	1.90	198	1162.10	0.0001
8	0.34	1.48	160	975.67	0.0000
9	0.48	1.30	124	786.06	0.0200
10	0.65	1.01	90	593.43	0.4600
11	0.81	0.77	58	398.00	0.8800
12	0.93	0.57	28	200.00	0.9600

Table D-10. Canonical correlations and the eigenvalues obtained by CDA of reduced sensors, their squares and their approximate standard errors for controlled atmosphere experiment

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation	Eigenvalue	Proportion	Cumulative
1	**0.88**	0.86	0.02	0.78	3.50	0.62	**0.62**
2	**0.76**	0.72	0.03	0.58	1.37	0.24	**0.87**
3	0.66	0.60	0.04	0.43	0.75	0.13	1.00
4	0.00	-	0.07	0.00	0.00	0.00	1.00

Table D-11.Results of statistical tests to see how many canonical correlations are significantly different from zero for reduced sensors data of experiment I and raw canonical coefficients for reduced sensors of controlled atmosphere experiment

	Likelihood	Approximate						
	Ratio	F Value	Num DF	Den DF	Pr > F	Variable	Can1	Can2
1	0.05	8.45	93	473	0.0001	T_258	-5.90	-4.77
2	0.24	5.49	60	318	0.0001	T_264	-3.52	4.09
3	0.57	4.15	29	160	0.0001	T_262	12.35	-2.40

Table D-12. The values of canonical correlations of color blocks and their squares and their approximate standard errors of experiment I

Canonical variable	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.96	0.96	0.00	0.93
2	0.88	0.85	0.01	0.77
3	0.86	0.83	0.01	0.73
4	0.82	-	0.02	0.68
5	0.81	-	0.02	0.66
6	0.76	0.72	0.02	0.57
7	0.69	0.64	0.03	0.48
8	0.59	0.11	0.02	0.92
9	0.47	0.06	0.02	0.93
10	0.41	0.13	0.01	0.95

Table D-13. The eigenvalues, which are the estimated variances of respective canonical variables obtained by CDA for color data set of experiment I.

Canonical Variable	Eigenvalue	Difference	Proportion	Cumulative
1	13.45	10.16	0.47	0.47
2	3.29	0.56	0.11	0.58
3	2.73	0.62	0.10	0.68
4	2.11	0.14	0.07	0.75
5	1.97	0.63	0.07	0.82
6	1.34	0.43	0.05	0.87
7	0.92	0.33	0.03	0.90
8	0.59	0.11	0.02	0.92
9	0.47	0.06	0.02	0.93
10	0.41	0.13	0.01	0.95

Table D-14. Results of statistical tests to see how many canonical correlations are significantly different from zero for color data of experiment I

Canonical Correlation	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.00	5.33	961.00	7235.50	0.0001
2	0.00	4.15	900.00	7017.80	0.0001
3	0.00	3.63	841.00	6799.10	0.0001
4	0.00	3.14	784.00	6579.40	0.0001
5	0.01	2.70	729.00	6358.80	0.0001
6	0.02	2.25	676.00	6137.20	0.0001
7	0.04	1.89	625.00	5914.60	0.0001
8	0.08	1.61	576.00	5691.10	0.0001
9	0.12	1.43	529.00	5466.60	0.0001
10	0.18	1.26	484.00	5241.20	0.0002

Table D-15. Raw canonical coefficients for color blocks of experiment I

Colors	Can1	Can2	Can3
c152	0.39	1.03	**-0.03**
c153	0.05	0.73	1.30
c154	0.15	0.13	0.15
c224	1.23	**-1.01**	0.47
c225	**-0.37**	0.60	0.56
c226	0.26	0.06	**-0.24**
c227	**-0.24**	0.97	1.75
c233	1.22	0.61	1.47
c296	0.61	**-2.30**	3.37
c297	1.01	**-0.96**	**-0.90**
c298	**-0.05**	0.10	0.33
c299	0.17	0.54	0.26
c369	0.09	0.28	1.85
c370	1.57	0.15	**-0.94**
c371	0.55	**-0.49**	0.29
c372	**-0.35**	0.41	0.62
c433	0.38	**-0.24**	2.57
c434	**-0.04**	0.10	0.54
c441	0.43	0.66	**-0.42**
c442	0.53	0.57	**-0.45**
c443	**-0.03**	0.01	0.36
c444	**-0.27**	0.79	**-0.35**
c445	0.30	0.20	**-0.20**
c446	0.73	**-0.95**	**-0.38**
c505	0.79	0.41	0.42
c506	**-0.06**	0.13	**-0.13**
c507	0.32	0.21	0.16
c508	0.09	**-0.01**	0.05
c509	0.18	0.04	0.09
c510	0.11	0.06	0.08
c511	0.10	0.08	0.10

Table D-16. The values of canonical correlations of combined color blocks, their squares and their approximate standard errors of experiment I

Canonical Variable	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.93	0.92	0.01	0.86
2	0.70	0.68	0.03	0.49
3	0.38	0.30	0.04	0.14

Table D-17. The eigenvalues obtained by CDA for combined color data set of experiment I.

Canonical Variable	Eigenvalue	Difference	Proportion	Cumulative
1	6.46	5.47	0.85	**0.85**
2	0.99	0.82	0.13	**0.98**
3	0.17	-	0.02	1.00

Table D-18. Results of statistical tests to see how many canonical correlations are significantly different from zero for color data of experiment I

Canonical correlation	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.06	18.00	93	1048	0.0001
2	0.42	6.15	60	702	0.0001
3	0.85	2.05	29	352	0.0014

Table D-19. Raw Canonical Coefficients for combined color blocks of experiment I

Reduced colors	Can1	Can2	Can3
A	0.03	0.09	0.24
B	0.72	-0.52	0.65
C	1.72	2.56	-0.04

Table D-20. The values of canonical correlations of sensors, their squares and their approximate standard errors of experiment II

Canonical Variables	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.98	-	0.00	0.97
2	0.98	-	0.00	0.96
3	0.92	0.90	0.01	0.84
4	0.83	0.78	0.02	0.69
5	0.81	-	0.02	0.66
6	0.65	0.56	0.04	0.42
7	0.60	0.51	0.05	0.36
8	0.51	0.39	0.05	0.26
9	0.47	0.39	0.06	0.22
10	0.40	0.27	0.06	0.16
11	0.37	-	0.06	0.14
12	0.25	0.10	0.07	0.06

Table D-21. The eigenvalues, which are the estimated variances of respective canonical variables obtained by CDA for e-nose data set of experiment II.

Canonical Variables	Eigenvalue	Difference	Proportion	Cumulative
1	**31.37**	**4.78**	**0.45**	**0.45**
2	**26.58**	**21.38**	**0.38**	**0.83**
3	5.20	2.99	0.07	0.91
4	2.21	0.28	0.03	0.94
5	1.94	1.20	0.03	0.97
6	0.73	0.18	0.01	0.98
7	0.55	0.19	0.01	0.98
8	0.36	0.07	0.01	0.99
9	0.29	0.09	0.00	0.99
10	0.19	0.03	0.00	1.00
11	0.16	0.10	0.00	1.00
12	0.07	-	0.00	1.00

Table D-22. Results of statistical tests to see how many canonical correlations are significantly different from zero for e-nose data of experiment II

Canonical Correlation	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	**0.00**	**9.80**	**372**	**1710.50**	**0.0001**
2	**0.00**	**7.02**	**330**	**1585.60**	**0.0001**
3	**0.00**	**4.44**	**290**	**1457.90**	**0.0001**
4	**0.02**	**3.30**	**252**	**1327.20**	**0.0001**
5	**0.05**	**2.65**	**216**	**1193.30**	**0.0001**
6	**0.14**	**1.92**	**182**	**1056.20**	**0.0001**
7	**0.25**	**1.63**	**150**	**915.66**	**0.0001**
8	**0.39**	**1.37**	**120**	**771.59**	**0.0088**
9	0.53	1.19	92	623.92	0.1180
10	0.68	1.00	66	472.69	0.4869
11	0.81	0.85	42	318.00	0.7364
12	0.94	0.52	20	160.00	0.9500

Table D-23. The values of canonical correlations and the eigenvalues obtained by CDA of reduced sensors, their squares and their approximate standard errors for experiment II.

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation	Eigenvalue	Proportion	Cumulative
1	0.98	0.97	0.00	0.95	**20.03**	**0.93**	**0.93**
2	0.67	0.58	0.04	0.45	**0.82**	**0.04**	**0.97**
3	0.65	-	0.04	0.42	0.72	0.03	1.00
4	0.00	-	0.07	0.00	0.00	0.00	1.00

Table D-24. Results of statistical tests to see how many canonical correlations are significantly different from zero for reduced e-nose data and raw canonical coefficients for reduced sensors of experiment II

	Likelihood Ratio	Approximate						
		F Value	Num DF	Den DF	Pr > F	Variable	Can1	Can2
1	0.01	15.53	93	473	**0.0001**	T_258	-11.06	0.98
2	0.32	4.07	60	318	**0.0001**	T_301	10.52	-13.46
3	0.58	3.97	29	160	**0.0001**	T_261	6.66	9.28

APPENDIX E
CANONICAL CORRELATION ANALYSIS

Controlled Atmosphere Experiment

Table E-1. Canonical correlation analysis among color blocks, yellow, green, and discoloration

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.99**	**0.99**	**0.00**	**0.99**
2	0.93	0.89	0.03	0.87
3	0.73	0.50	0.10	0.54
4	0.67	-	0.12	0.44

Table E-2. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	**0.00**	**2.24**	**52**	**17.60**	**0.03**
2	0.03	0.94	36	15.50	0.58
3	0.26	0.53	22	12.00	0.91
4	0.56	0.56	10	7.00	0.80

Table E-3. Standardized canonical coefficients between color and sensory data

Standardized Canonical Coefficients for the VAR Variables		
Selected sensory attributes	V1	V2
Yellow	-0.69	0.17
Green	-0.06	-0.54
Browning	**0.81**	-0.77
Discoloration	0.11	1.36
Standardized Canonical Coefficients for the WITH Variables		
Color blocks	W1	W2
C80	-0.05	-0.23
C152	0.35	0.15
C216	**-3.97**	4.26
C224	-0.55	-0.97
C288	-1.88	2.98
C296	**2.98**	-0.36
C297	1.25	1.48
C360	**8.90**	-9.87
C369	-1.92	-0.55
C432	**-2.08**	0.93
C433	**-3.12**	3.42
C444	-0.42	-0.06
C509	0.04	0.61

Table E-4. Canonical correlation analysis among all sensors, off-odor and fresh zucchini aroma

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.97**	0.96	0.01	**0.95**
2	0.72	0.56	0.11	0.51

Table E-5. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.03	3.08	24	14	**0.0163**
2	0.49	0.76	11	8	0.6684

Table E-6. Standardized canonical coefficients among e-nose, off-odor and fresh zucchini aroma

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
Off-odor	**1.18**	3.63
Fresh zucchini aroma	0.19	3.82
Standardized Canonical Coefficients for the WITH Variables		
Sensors	W1	W2
T_301	0.48	-4.88
T_298	**-12.25**	-48.44
T_297	**8.60**	52.46
T_283	**14.84**	1.72
T_278	-2.20	1.83
T_264	**-4.15**	-18.77
T_263	**-4.79**	14.01
T_262	**-6.52**	-9.25
T_261	**10.34**	4.76
T_260	-1.71	12.23
T_259	-1.95	-2.71
T_258	-0.90	-3.27

Table E-7. Canonical correlation analysis among reduced sensors, off-odor and fresh zucchini aroma.

	Canonical correlation	Adjusted canonical correlation	Approximate standard error	Squared canonical correlation
1	**0.86**	0.84	0.06	**0.74**
2	0.54	0.50	0.16	0.29

Table E-8. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.18	5.05	8	30	**0.0005**
2	0.70	2.21	3	16	0.1263

Table E-9. Standardized canonical coefficients among selected sensors, off-odor and fresh zucchini aroma

Standardized Canonical Coefficients for the VAR Variables	
Sensory attributes	V1
Off-odor	**0.55**
Fresh zucchini aroma	-0.46
Standardized Canonical Coefficients for the WITH Variables	
Sensors	W1
T_298	-1.65
T_297	-0.01
T_259	**0.43**
T_258	**1.44**

Table E-10. Canonical correlation analysis between all sensors and microbial count

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.99	0.99	0.00	0.99

Table E-11. Results of statistical tests to see how many of canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.01	52.29	12	8	0.0001

Table E-12. Standardized canonical coefficients between all sensors and microbial count

Standardized Canonical Coefficients for the VAR Variables	
Microbial analysis	V1
microbial count	1.00
Standardized Canonical Coefficients for the WITH Variables	
Sensors	W1
T_301	0.04
T_298	**-9.17**
T_297	**7.61**
T_283	**7.32**
T_278	0.46
T_264	**-8.90**
T_263	2.53
T_262	**-8.01**
T_261	**10.79**
T_260	**-5.19**
T_259	**2.25**
T_258	0.09

Table E-13. Canonical correlation analysis between reduced sensors and microbial count

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.94	0.94	0.02	0.89

Table E-14. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	0.11	31.89	4	16	0.0001

Table E-15. Standardized canonical coefficients between reduced sensors and microbial count

Standardized Canonical Coefficients for the VAR Variables	
Microbial analysis	V1
microbial count	1.00
Standardized Canonical Coefficients for the WITH Variables	
Sensors	W1
T_298	-0.08
T_297	-1.82
T_259	0.41
T_258	1.45

Table E-16. Canonical correlation analysis between selected sensory attributes and microbial count

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.92	0.92	0.03	0.85

Table E-17. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	0.15	51.38	2	18	0.0001

Table E-18. Standardized canonical coefficients between selected sensory attributes and microbial count

Standardized Canonical Coefficients for the VAR Variables	
Sensory attributes	V1
Off-odor	0.53
Fresh zucchini aroma	-0.47
Standardized Canonical Coefficients for the WITH Variables	
Microbial analysis	W1
microbial count	1.00

Table E-19. Canonical correlation analysis between Instron and sensory

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.87**	0.86	0.06	0.75
2	0.18	-	0.23	0.03

Table E-20. Results of statistical tests to see how many of canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.23	7.9	4	30	**0.0002**
2	0.96	0.54	1	16	0.4718

Table E-21. Standardized canonical coefficients between selected sensory attributes and Instron

Standardized Canonical Coefficients for the VAR Variables		
Sensory	V1	V2
Hard	0.85	-3.99
Crisp	0.16	4.07
Standardized Canonical Coefficients for the WITH Variables		
Instron	W1	W2
Shear	0.82	-1.23
Comp	0.23	1.46

Expeiment I

Table E-22. Canonical correlation analysis between color and sensory data

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.90**	0.85	0.03	0.80
2	0.52	0.31	0.11	0.27

Table E-23. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.14	2.77	28	48	**0.0009**
2	0.72	0.72	13	25	0.7303

Table E-24. Standardized canonical coefficients between color and sensory data

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
White-yellow	-0.35	2.11
Degree of transparency	1.30	-1.70
Standardized Canonical Coefficients for the WITH Variables		
Color Blocks	W1	W2
c154	-0.68	0.33
c224	0.65	-0.99
c225	-0.15	0.04
c226	0.21	-0.44
c297	-0.37	0.36
c299	0.23	-0.73
c372	0.32	0.92
c443	-0.09	0.25
c445	0.02	-0.33
c507	-0.02	0.58
c508	0.37	-1.22
c509	-0.24	0.13
c510	-0.81	-0.60

Table E-25. Canonical correlation analysis between e-nose and sensory

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.94**	0.93	0.02	0.89
2	0.71	0.63	0.08	0.50

Table E-26. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	0.05	7.08	24	52	**0.0001**
2	0.49	2.49	11	27	0.0262

Table E-27. Standardized canonical coefficients among e-nose, off-odor and fresh zucchini aroma

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
Off-odor	0.85	1.28
Fresh zucchini aroma	-0.19	1.52
Standardized Canonical Coefficients for the WITH Variables		
Sensors	W1	W2
T_301	-0.58	4.56
T_298	**1.44**	-8.24
T_297	-2.43	6.10
T_283	**2.95**	-3.41
T_278	-0.75	-0.67
T_264	-1.78	6.20
T_263	0.79	-3.53
T_262	0.87	-2.00
T_261	0.83	-3.17
T_260	-3.09	1.99
T_259	-0.29	0.79
T_258	**2.03**	2.03

Table E-28. Canonical correlation analysis among reduced sensors, off-odor and fresh zucchini aroma

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.71**	0.65	0.08	0.50
2	0.56	0.54	0.11	0.31

Table E-29. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	0.34	4.69	10	66	**0.0001**
2	0.68	3.85	4	34	0.0109

Table E-30. Standardized canonical coefficients among selected sensors, off-odor and fresh zucchini aroma

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
Off-odor	**1.08**	1.09
Fresh zucchini aroma	0.11	1.53
Standardized Canonical Coefficients for the WITH Variables		
Reduced sensors	W1	W2
T_298	**-3.63**	1.08
T_264	0.72	1.10
T_263	**1.15**	-0.63
T_262	**-1.24**	-0.85
T_258	**3.11**	-0.20

Table E-31. Canonical correlation analysis between all sensors and microbial count

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.95**	0.94	0.02	0.90

Table 4-E-32. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.09	20.75	12	27	**0.0001**

Table E-33. Standardized canonical coefficients between all sensors and microbial count

Standardized Canonical Coefficients for the VAR Variables	
Microbial Analysis	V1
microbial count	1.00
Standardized Canonical Coefficients for the WITH Variables	
Sensors	W1
T_301	-1.08
T_298	**5.42**
T_297	**-5.30**
T_283	0.63
T_278	0.97
T_264	-1.38
T_263	**1.05**
T_262	0.96
T_261	**1.49**
T_260	**-5.28**
T_259	**2.07**
T_258	0.33

Table E-34. Canonical correlation analysis between reduced sensors and microbial count

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.69**	0.65	0.08	0.47

Table E-35. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	0.528255	6.07	5	34	**0.0004**

Table E-36. Standardized canonical coefficients between reduced sensors and microbial count

Standardized Canonical for the VAR Variables	
Microbial analysis	V1
microbial count	1.00
Standardized Canonical for the WITH Variables	
Reduced sensors	W1
T_298	**-3.81**
T_264	0.04
T_263	1.64
T_262	-1.00
T_258	**2.94**

Table E-37. Canonical correlation analysis between selected sensory attributes and microbial count

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.83**	0.83	0.05	0.69

Table E-38. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	0.30	41.82	2	37	**0.0001**

Table E-39. Standardized canonical coefficients between selected sensory attributes and microbial count

Standardized Canonical for the VAR Variables	
Sensory attributes	V1
Off-odor	0.49
Fresh zucchini aroma	-0.57
Standardized Canonical for the WITH Variables	
Microbial analysis	W1
microbial count	1.00

Table E-40. Canonical correlation analysis between selected sensory attributes (Hardness, Crispness, Surface breakdown, Dry-wet) and instron

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.61**	0.55	0.10	0.37
2	0.37	0.34	0.14	0.14

Table E-41. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood	Approximate			
	Ratio	F Value	Num DF	Den DF	Pr > F
1	0.54	3.03	8	68	**0.0056**
2	0.85	1.90	3	35	0.1472

Table E-42. Standardized canonical coefficients between selected sensory attributes and Instron

Standardized Canonical for the VAR Variables		
Sensory attributes	V1	V2
Surface breakdown	0.09	-1.43
dry-wet	-1.35	1.49
hardness	0.64	1.11
crispness	-0.43	0.45
Standardized Canonical for the WITH Variables		
Instron	W1	W2
small blade	-0.49	1.01
big blade	1.12	-0.02

Table E-43. Canonical correlation analysis between selected sensory attributes (Hardness, Crispness) and instron

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.34	0.27	0.14	0.12
2	0.14	-	0.16	0.02

Table E-44. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.86	1.35	4	72	0.2605
2	0.98	0.69	1	37	0.4113

Table E-45. Standardized canonical coefficients between selected sensory attributes and Instron

Standardized Canonical for the VAR Variables		
Sensory attributes	V1	V2
hardness	1.22	-0.99
crispness	0.31	-1.54
Standardized Canonical for the WITH Variables		
Instron	W1	W2
small blade	0.89	-0.68
big blade	0.20	1.10

Experiment II

Table E-46. Canonical correlation analysis among color data , white-yellow and degree of transparency

	Canonical Correlation	Adjusted Canonical Correlation	Ap proximate Standard Error	Squared Canonical Correlation
1	**0.99**	0.99	0.0014	**0.99**
2	0.86	0.79	0.0440	0.75

Table E-47. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.00	12.48	38	22	**0.0001**
2	0.24	2.02	18	12	0.1088

Table E-48. Standardized canonical coefficients between color and sensory data

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
white-yellow	0.40	-14.49
degree of transparency	-0.40	14.55
Standardized Canonical Coefficients for the WITH Variables		
Colors	W1	W2
c224	-0.35	0.06
c233	-0.04	-0.11
c296	0.22	-6.89
c297	-0.08	0.41
c369	-2.04	28.33
c370	0.13	-1.23
c441	-0.03	-2.54
c442	3.86	-24.75
c443	-0.12	1.29
c444	0.12	-2.09
c506	-2.05	24.54
c507	-1.89	-12.30
c510	-0.22	-8.46

Table E-49. Canonical correlation analysis among all sensors, off-odor and fresh zucchini aroma

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.95**	0.93	0.017026	**0.90**
2	**0.87**	0.84	0.041486	**0.76**

Table E-50. Results of statistical tests to see how many of canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	**0.02**	8.64	24	36	**0.0001**
2	**0.23**	5.75	11	19	**0.0005**

Table E-51. Standardized canonical coefficients among e-nose, off-odor and fresh zucchini aroma

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
off-odor	0.55	4.61
Fresh zucchini aroma	-0.44	4.62
Standardized Canonical Coefficients for the WITH Variables		
Sensors	W1	W2
T_301	-0.71	-1.43
T_298	-0.71	7.11
T_297	-0.08	-8.63
T_283	-0.68	2.23
T_278	0.45	0.74
T_264	-1.37	-1.83
T_263	3.32	3.74
T_262	-3.53	0.02
T_261	1.45	-2.33
T_260	0.66	5.65
T_259	0.02	-4.97
T_258	1.22	0.12

Table E-52. Canonical correlation analysis among two sensors, off-odor and fresh zucchini aroma

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.91	0.90	0.03	0.82
2	0.43	-	0.15	0.19

Table E-53. Results of statistical tests to see how many canonical correlations are significantly different from zero

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.14	22.77	4	56	0.0001
2	0.81	6.65	1	29	0.0152

Table E-54. Standardized canonical coefficients among e-nose, off-odor and fresh zucchini aroma

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
off-odor	0.0244	4.6429
fresh zucchini aroma	-0.9761	4.5392
Standardized Canonical Coefficients for the WITH Variables		
Sensors	W1	W2
T_264	-1.0133	0.4352
T_258	0.8219	0.7353

Table E-55. Canonical correlation analysis and Results of statistical tests to see how many canonical correlations are significantly different from zero from microbial count and all sensor readings

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation	
1	0.93	0.919258	0.0214	0.88	
	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.11	11.93	12	19	0.0001

Table E-56. Standardized canonical coefficients between microbial count and all sensors of e-nose data

Standardized Canonical Coefficients for the VAR Variables	
Microbial analysis	V1
Microbial count	1.00
Standardized Canonical Coefficients for the WITH Variables	
Sensors	W1
T_301	-1.53
T_298	-1.62
T_297	**2.19**
T_283	**2.24**
T_278	-1.77
T_264	-1.70
T_263	-0.48
T_262	**2.58**
T_261	**1.45**
T_260	-2.22
T_259	-0.28
T_258	1.02

Table E-57. Canonical correlation analysis and Results of statistical tests to see how many canonical correlations are significantly different from zero from microbial count and two sensor readings

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation	
1	0.86	0.867668	0.044042	0.75	
	Likelihood Ratio	Approximate			
		F Value	Num DF De	Den DF	Pr > F
1	0.24	44.63	2	29	0.0001

Table E-58. Standardized canonical coefficients between microbial count and two sensors of e-nose data

Standardized Canonical Coefficients for the VAR Variables	
Microbial analysis	V1
microbial count	1.00
Standardized Canonical Coefficients for the WITH Variables	
Reduced sensors	W1
T_264	-1.04
T_258	0.76

Table E-59. Canonical correlation analysis and results of statistical tests to see how many canonical correlations are significantly different from zero from selected sensory attributes and texture data

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	0.88	0.88	0.04	0.79
2	0.07	.	0.18	0.01

	Likelihood Ratio	Approximate			
		F Value	Num DF	Den DF	Pr > F
1	0.21	16.37	4	56	0.0001
2	1.00	0.15	1	29	0.7041

Table E-60. Standardized canonical coefficients between selected sensory attributes and texture data

Standardized Canonical Coefficients for the VAR Variables	
Sensory attributes	V1
hardness	-0.8494
crispness	0.1531
Standardized Canonical Coefficients for the WITH Variables	
Blade type	W1
Small blade	0.3112
Big blade	0.7029

Table E-61. Canonical correlation analysis and results of statistical tests to see how many canonical correlations are significantly different from zero from all sensory attributes and instron data

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation
1	**0.90**	0.89	0.03	0.81
2	0.26	0.16	0.17	0.07

	Likelihood Ratio	Approximate			
		F Value	Num DF	DF	Pr > F
1	0.18	8.85	8	52	0.0001
2	0.93	0.68	3	27	0.5739

Table E-62. Standardized canonical coefficients between selected sensory attributes and Instron data

Standardized Canonical Coefficients for the VAR Variables		
Sensory attributes	V1	V2
Surface breakdown	-0.60	-2.32
dry-wet	**0.91**	5.53
hardness	**-1.16**	-3.86
crispness	0.14	-0.87
Standardized Canonical Coefficients for the WITH Variables		
Blade type	W1	W2
Small blade	0.18	-2.82
Big blade	**0.83**	2.70

Table E-63. Canonical correlation analysis and results of statistical tests to see how many of canonical correlations are significantly different from zero from all sensory attributes and microbial count data

	Canonical Correlation	Adjusted Canonical Correlation	Approximate Standard Error	Squared Canonical Correlation	
1	0.89	0.89	0.04	0.79	
	Likelihood Ratio	Approximate			
		F Value	Num DF	DF	Pr > F
1	0.21	54.02	2	29	0.0001

Table E-64. Standardized canonical coefficients between selected sensory attributes and microbial count data

Standardized Canonical Coefficients for the VAR Variables	
selected sensory attributes	V1
off-odor	-1.32
fresh zucchini aroma	-2.25
Standardized Canonical Coefficients for the WITH Variables	
Microbial analysis	W1
microbial count	1.00

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BIOGRAPHICAL SKETCH

Necla Demir was born in Ankara, Turkey, in 1968. She completed her elementary, middle and high school education in Ankara. After her graduation she was admitted to Ankara University, College of Agriculture, Department of Food Science and Technology in 1986 and graduated from the University in 1990 as an agricultural engineer. She earned her master's degree in the same department. Then, she took the nationwide exam for the opportunity to study in the USA for both the master's and Ph.D. degrees. She spent 3 months at Florida State University for English education and started her master's degree program at Clemson University in August 1995. She received an M.S. degree in August 1997. Then, she transferred to the University of Florida, Department of Food Science and Human Nutrition in August 1997 to earn a Ph.D. degree. Necla expects to receive her Doctor of Philosophy degree in August 2002. She plans to return to Turkey to become a faculty member in Süleyman Demirel University in Isparta, after graduation.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Balaban

Murat O. Balaban, Chair
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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JKBrecht

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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